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WATER QUALITY CRITERIA. REPORT OF THE NATIONAL TECHNICAL ADVISORY COMMITTEE TO THE SECRETARY OF THE INTERIOR

Federal Water Pollution Control Administration
Washington, D. C.

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Water Quality Criteria

Report of the
National Technical Advisory Committee
to the
Secretary of the Interior

APRIL 1, 1968
WASHINGTON, D.C.

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

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LETTER OF TRANSMITTAL

Hon. Stewart L. Udall, Secretary
U.S. Department of the Interior

This letter transmits the report of the National Technical Advisory Committee on Water Quality Criteria. The chairmen of the five Subcommittees are to be commended for an excellent job in pulling together a mass of information and coordinating the efforts of the members to complete the report by the requested date of June 30, 1968.

This volume constitutes the most comprehensive document on water quality requirements to date, and as such, will be used as a basic reference by groups and agencies engaged in water quality studies and standards setting activities. At the same time, the Committee members and I wish to emphasize that this report is not sufficiently conclusive or inclusive to serve as the only guide in determining water quality criteria or requirements. Regional variations in climate, topography, hydrology, geology, and other factors must be considered in applying the criteria offered by the Committee to the establishment of water quality standards in specific localities.

I would also like to note that the Committee members have occasionally departed from the task of developing water quality criteria, with which you charged them, to make recommendations which are more properly the province of regulatory agency policy makers or designers of pollution abatement facilities. A few examples are:

1. A recommendation that all waters, except those adjacent to waste outfalls, provide for the maintenance and production of fish.
2. Recommendations of engineering design criteria for waste treatment plants.
3. A recommendation that incineration replace ocean disposal of sludge solids.

The tendency to consider broad issues of policy and design criteria was perhaps inevitable. While the mission was directed at water quality requirements, it was easy for the experts to wander and propose approaches that attempt to account for uncertainties and disagreements concerning scientific criteria. It is to the great credit of the chairmen that they were able to properly maintain primary attention on water quality criteria rather than the other two major components of water quality standards—water use designations and implementation and enforcement plans.

This report is as valuable for what it does not say as for what it does say. The work of the Committee illuminates the fact that the unknowns still far exceed the knowns in water quality requirements—even to the experts. Therefore, requirements should be applied with the best of judgments. One of the most valuable aspects of the Committee's work was the examination of research needs and the guidance offered in such needs. A report of research needs is published as a separate document.

The FWPCA is grateful to the many participating organizations and individuals who comprised the Committee. They are to be congratulated for their cooperation and enthusiasm in this monumental task.

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Commissioner

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preface

THE FEDERAL WATER POLLUTION CONTROL ACT, as amended by the Water Quality Act of 1965, authorizes the States and the Federal Government to establish water quality standards for interstate (including coastal) waters by June 30, 1967. The water quality standards submitted by the States are subject to review by the Department of the Interior and, if found consistent with Paragraph 3 of Section 10 of the Act, will be approved as Federal standards by the Secretary of the Interior.

Paragraph 3, Section 10, reads as follows:

> Standards of quality established pursuant to this subsection shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of this Act. In establishing such standards the Secretary, the Hearing Board, or the appropriate state authority shall take into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other legitimate uses.

If a State does not adopt water quality standards consistent with the above paragraph, the Act provides the Secretary with the opportunity to set the standards.

On February 27, 1967, the Secretary established the first National Technical Advisory Committee on Water Quality Criteria to the Federal Water Pollution Control Administration. The Committee's principal function was to collect into one volume a basic foundation of water quality criteria. A smaller but equally important function was to develop a report on research needs. This latter report will appear as a separate publication. The Committee was subdivided to develop criteria for five general areas of water use: (1) Recreation and Aesthetics; (2) Public Water Supplies; (3) Fish, Other Aquatic Life, and Wildlife; (4) Agriculture; and (5) Industry.

An interim report was printed and presented to the Secretary of the Interior on June 30, 1967. It was prepared primarily for two purposes: to assist in setting and evaluating standards and for Committee review and comment.

After all the comments and revisions were considered, the various subcommittees accepted a final version in the form here presented. Evaluation by knowledgeable agencies and individuals is welcomed and any one who wishes to make comments should forward them to:

Water Quality Standards Staff
Federal Water Pollution Control Administration
U.S. Department of the Interior
633 Indiana Avenue NW.
Washington, D.C. 20242

introduction

THE FWPCA is grateful for the assistance of the Committee in implementing the Federal Water Pollution Control Act by recommending criteria for the various legitimate water uses.

One troublesome problem encountered in the initial meetings of the Committee was that of semantics. The Committee faced the task of sorting out meanings among the terms "criteria" and "standards." Regardless of any other uses of the words, the following definitions are considered appropriate:

> *Standard*—a plan that is established by governmental authority as a program for water pollution prevention and abatement.
>
> *Criteria*—a scientific requirement on which a decision or judgment may be based concerning the suitability of water quality to support a designated use.

The standards adopted by the States include water use classifications, criteria necessary to support these uses, and a plan for implementation and enforcement. Occasionally, among water pollution control authorities, the words "criteria" and "requirement" are used interchangeably. The same can be said for the words "standards" and "objectives."

The Federal Water Pollution Control Act authorizes the States to set standards. Quality characteristics of a physical, chemical, or biological nature demanded by aquatic life, industrial process, or other use, are requirements or criteria. This Report of the National Technical Advisory Committee concerns criteria—a significant part of water quality standards. The Committee considered the water use criteria set forth in this report with the objective of assisting the State and Federal agencies in setting and evaluating standards so they can meet water pollution abatement objectives.

The Committee was concerned about several issues relating to water quality standards for the control and abatement of water pollution. Foremost among these is the lack of adequate knowledge concerning many of the quality characteristics upon which criteria and, hence, standards should be based. The unknowns still outweigh the knowns. Complicating factors in setting standards are varying natural conditions affecting water quality, such as climate, geography, and geology of a specific location. The Committee does not want to be dogmatic in recommending these criteria. They are meant as guidelines only, to be used in conjunction with a thorough knowledge of local conditions. Further, it is anticipated that future research will provide considerable basis for refinements in the recommendations.

The Committee recognizes that the protection of water quality for legitimate uses requires far more than scientific information. There is an urgent need for data collected from systematic surveillance of waters and waste sources and for an expanded research effort. Research needs are described in a separate document.

Achieving water quality goals, however, requires more than research and data collection. It will depend on people: alert and responsible administrators at all levels of government and industry, well-trained scientists, engineers, and technicians, sympathetic legislators and stockholders, and an informed public.

Determining water quality criteria for various water uses is an important step in solving the Nation's water pollution problems. Along with vigorous implementation programs, it is a necessary step in achieving water quality management on a scientific basis. The Committee firmly believes that preserving and improving the quality of our water resources is well worth our best efforts.

Federal Water Pollution Control
Administration

Washington, D.C.
April 1, 1968

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Section I

recreation and aesthetics

foreword

THE NATIONAL Technical Advisory Subcommittee for Research and Aesthetics has been asked to—

(1) recommend water quality criteria for recreation and aesthetic uses; and

(2) identify research needs and priorities relating to water quality for recreation and aesthetic uses.

This report is addressed to the first of these assignments. It includes observations on aesthetic and recreation values as these are understood by the Subcommittee. Criteria—descriptive and numerical—are based upon evaluation of existing information by members of the Subcommittee and others whose counsel has been sought informally. There are serious gaps, and considerable conflict, in available information. Research recommendations are offered in a separate paper.

The Subcommittee is grateful for the opportunity to assist in implementing the Water Quality Act of 1965 by recommending criteria for aesthetic and recreation purposes. The Subcommittee notes, however, that the protection of water quality for desired uses requires far more than technical data. There is urgent need for systematic surveillance (traditional sanitary surveys broadened to include aesthetic qualities) of waters and of waste sources to make effective use of criteria in practice. And in the last analysis, accomplishment of water quality goals will depend on people: alert and responsible administrators at all levels of government and industry, well-trained scientists, engineers, and technicians, sympathetic legislators and stockholders, and an informed public.

With this somewhat modest view of its assignment and its performance, the Subcommittee is pleased to offer this report. In the interest of orderly exposition, the Subcommittee has chosen to consider aesthetics first, followed by recreation.

NOTES

1. The Subcommittee has found that criteria are needed for water quality management for *de facto*, as well as designated, water uses. This finding is reflected throughout the report and particularly in criteria for recreation.

2. The Subcommittee has not proposed delicate gradations in criteria, assuming that in natural waters—even for specific uses at specific points—management necessarily involves sizable reaches of water.

3. The recommendations in this report should be considered as subject to periodic adjustment as better information becomes available.

summary of recommendations

Aesthetics

A. *General Requirements*
   I. All surface waters should be capable of supporting life forms of aesthetic value.
   II. Surface waters should be free of substances attributable to discharges or wastes as follows:
      (a) Materials that will settle to form objectionable deposits.
      (b) Floating debris, oil, scum, and other matter.
      (c) Substances producing objectionable color, odor, taste, or turbidity.
      (d) Materials, including radionuclides, in concentrations or combinations which are toxic or which produce undesirable physiological responses in human, fish, and other animal life and plants.
      (e) Substances and conditions or combinations thereof in concentrations which produce undesirable aquatic life.

B. *Desirable Additional Requirements*
   I. The positive aesthetic values of water should be attained through continuous enhancement of water quality.
   II. The aesthetic values of unique or outstanding waters should be recognized and protected by development of appropriate criteria for each individual case.

Recreation

A. *General Recreational Use of Surface Waters*
   I. Surface waters, with specific and limited exceptions, should be suitable for human use in recreation activities not involving significant risks of ingestion without reference to official designation of recreation as a water use. For this purpose, in addition to aesthetic criteria, surface waters should be maintained in a condition to minimize potential contamination by utilizing fecal coliform criteria for monitoring. In the absence of local epidemiological experience, the Subcommittee suggests an average not to exceed 2,000 fecal coliforms per 100 ml and a maximum of 4,000 per 100 ml, except in specified mixing zones adjacent to outfalls.
   II. Surface waters, with specific and limited exceptions, should be of such quality as to provide for the enjoyment of recreation activities based upon the utilization of fishes, waterfowl, and other forms of life without reference to official designation of use. The Subcommittee recommends by reference criteria developed by the National Technical Advisory Subcommittee on Fish, Other Aquatic Life, and Wildlife for guidance relative to various species and waters.
   III. Species available for harvest by recreation users should be fit for human consumption. In areas where taking of mollusks is a recreational activity, the criteria shall be guided by the U.S. Public Health Service manual, "Sanitation of Shellfish Growing Areas," 1965 revision.

B. *Enhancement of Recreation Value of Waters Designated for Recreation Uses Other Than Primary Contact Recreation*
   I. In waters designated for recreation use other than primary contact recreation, the fecal coliform content, as determined by either multiple-tube fermentation or membrane filter techniques, should not exceed a log mean of 1,000/100 ml, nor equal or exceed 2,000/100 ml in more than 10% of the samples.
   II. In waters designated for recreation use,

optimum conditions for recreation based upon utilization of fish, other aquatic life, and wildlife should apply, with specific and limited exceptions. The Subcommittee endorses by reference the criteria for these purposes recommended by the National Technical Advisory Subcommittee on Fish, Other Aquatic Life, and Wildlife.

C. *Primary Contact Recreation*

I. Criteria for mandatory factors.

(a) Fecal coliform should be used as the indicator organism for evaluating the microbiological suitability of recreation waters. As determined by multiple-tube fermentation or membrane filter procedures and based on a minimum of not less than five samples for any 30-day period of the recreation season, the fecal coliform content of primary contact recreation waters shall not exceed a log mean of 200/100 ml, nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 ml.

(b) In primary contact recreation waters, the pH should be within the range of 6.5–8.3 except when due to natural causes and in no case shall be less than 5.0 nor more than 9.0. When the pH is less than 6.5 or more than 8.3, discharge of substances which further increases unfavorable total acidity or alkalinity should be limited.

II. Criteria for desirable factors.

(a) For primary contact waters, clarity should be such that a Secchi disc is visible at a minimum depth of 4 feet. In "learn to swim" areas, the clarity should be such that a Secchi disc on the bottom is visible. In diving areas, the clarity shall equal the minimum required by safety standards, depending on the height of the diving platform or board.

(b) In primary contact recreation waters, except where caused by natural conditions, maximum water temperature should not exceed 85 F (30 C).

III. Marine waters

The Subcommittee suggests, as a general practice, application of a single set of criteria for fresh, estuarine, and marine waters.

aesthetics

Observations on aesthetic values

It is not surprising that water has occupied an important position in the concerns of man. The fate of tribes and nations, cities and civilizations has been determined by drought and flood, by abundance or scarcity of water since the earliest days of mankind.

Artists have reflected man's fascination with water. Literature and art of a variety of cultures dwell upon brooks, waves, waterfalls, and lakes as superlatives among the delights of the environment.

Aesthetically pleasing waters add to the quality of human experience. Water may be pleasant to look upon, to walk or rest beside, to contemplate. It may provide a variety of active recreation experience. It may enhance the visual scene wherever it appears, in cities or wilderness. It may enhance values of adjoining properties, public and private. It may provide a focal point of pride in the community.

The appearance of pollution and the fear of pollution reduces aesthetic value; the knowledge that water is clean enhances both direct and indirect aesthetic appreciation.

The Subcommittee is charged with recommending aesthetic criteria for water itself. But the Subcommittee notes that the aesthetic appeal of visual scenes in which water is an element involves the uses and activities on the water's surface; i.e., boats, ships, wildlife.

Thus the management of water for aesthetic purposes must be planned and executed in the context of the uses of the land, the shoreline, and the water surface.

It is clear that Americans are becoming increasingly concerned about aesthetic quality of the physical environment. And it seems probable that aesthetic expectations will rise with increases in education and leisure, and that these rising expectations will be reflected in continuing and accelerated public demand for "clean" water. The recent history of public policy in water pollution control would seem to support these observations.

On a number of occasions, the President has expressed a growing national concern for the quality of the environment and specifically for the quality of water resources. In his 1965 message on "The Natural Beauty of Our Country," the President said:

> A prime national goal must be an environment that is pleasing to the senses (as well as) healthy to live in.

In the same message, the President called for intensified action to clean up "waterways that were once sources of pleasure and beauty and recreation," but are now "objectionable to sight and smell," as well as dangerous for human contact. The concern of the new conservation, the President has said, "Is not just man's welfare, but the dignity of man's spirit."

Congress has affirmed and reaffirmed its determination to enhance water quality in a series of actions strengthening the Federal role in water pollution control and strengthening Federal support for water pollution control programs of State and local governments and industry.

In a number of States, political leaders and voters have overwhelmingly supported costly programs to restore water quality, with aesthetics—as well as recreation—as one of the values involved.

The recognition, identification, and protection of the aesthetic values and qualities of water should be an objective of all water quality management programs. Withdrawn water that is not consumed returns to the common supply. The retention of suitable characteristics, including aesthetic quality, in the common supply is more likely to be achieved through control of discharges at the source than by excessive dependence upon assimilation by receiving waters. The Subcommittee emphasizes the values that aesthetically pleasing water provides are most urgently needed where pollution problems are most difficult—in cities, and particularly in the central portions of cities where population and industry are likely to be most heavily concentrated.

Recommended criteria for aesthetic purposes

Recommendation: All surface waters should contribute to the support of life forms of aesthetic value.

This recommendation is made in recognition of the significance of fishes, waterfowl, and other water-dependent species to human aesthetic satisfaction.

Wildlife is a significant element of the aesthetics of the physical environment, adding beauty in a variety of forms and life to otherwise static scenes. Beyond the direct experience of viewing (which may include educational and recreational nature study) is the aesthetic satisfaction of knowing that these life forms are present. Conversely, periodic disruptions in the aquatic environment by pollution—reflected in fish kills, damage to waterfowl, odors, noxious vegetative growths—degrade aesthetic qualities and appreciation. These aesthetic losses extend beyond the periods during which the conditions may occur. A river that is offensive periodically will lose much of its aesthetic value until suitable quality conditions are restored—and maintained consistently.

This recommendation, as well as others relative to aesthetics, is to be applied in the context of local conditions.

Numerical criteria of the National Technical Advisory Subcommittee on Fish, Other Aquatic Life, and Wildlife will provide guidance for water management.

In addition to supporting life forms of aesthetic value, surface waters should themselves be aesthetically pleasing. Because natural conditions vary widely, the Subcommittee recommends a series of descriptive rather than numerical criteria for this purpose. The criteria are intended in general terms to provide for the protection of surface waters from substances or conditions which might degrade or tend to degrade the aesthetic quality of water from other than natural sources. In this context "natural sources" includes only substances or conditions which may affect water quality independent of human activities. Human activities which cause degradation from otherwise natural sources, such as accelerated erosion from surface disturbances, are not considered to be natural. The criteria are intended to cover degradation "from discharges or waste." This phrase is intended to cover pollution from all sources attributable to human activities whether carried in over-the-surface flow, point discharges, or subsurface drainage.

The word "free" in the list of minimum requirements is acknowledged to be a practical impossibility; the presence of pollutants in some degree is inevitable. The Subcommittee assumes that administrators and courts will interpret the term in a manner that will accomplish the purposes of the criteria.

Recommendation: Surface waters should be free of substances attributable to discharges or waste as follows:

(a) Materials that will settle to form objectionable deposits.
(b) Floating debris, oil, scum, and other matter.
(c) Substances producing objectionable color, odor, taste, or turbidity.
(d) Materials, including radionuclides, in concentrations or combinations which are toxic or which produce undesirable physiological responses in human, fish and other animal life, and plants.
(e) Substances and conditions or combinations thereof in concentrations which produce undesirable aquatic life.

Substances and conditions referred to in (e), above, would include factors such as excessive nutrients and temperature elevation. Undesirable aquatic life would include objectionable abundance of organisms such as a bloom of blue-green algae resulting from discharge of a waste with a high nutrient content and an elevated temperature. We would encourage the use of numerical limitations on nutrients in specific waters where present or future knowledge may permit or other water use requirements (e.g., public water supply) justify such actions. However, the Subcommittee feels their recommending numerical limitations that would meet the many varying requirements of aesthetics for individual waters and regions would result in nothing more than a welter of numbers.

The Subcommittee wishes to emphasize that aesthetic qualities—notably color and clarity—of natural waters vary sharply among regions and within regions or even on specific streams, lakes, reservoirs, bays, and estuaries. The recommended criteria are intended to be applied in the context of natural conditions.

The Subcommittee considered recommending numerical criteria for aesthetic uses. It concluded that numbers would add little to the usefulness of descriptive criteria because the effect of various substances on waters is so largely dependent on local conditions.

Quality above minimum requirements

The Subcommittee notes that "Guidelines for Establishing Water Quality Standards for Interstate Waters," published by the Department of the Interior in 1966, provides that "water quality standards should be designed to *enhance* (italics supplied) the quality of water" and "in no case will standards providing for less than existing water quality be acceptable."

Generally speaking—especially when psychological factors are considered—the aesthetic values of water are enhanced by continuing improvement in quality conditions in microbiological, chemical, and physical terms and reduced as quality declines. Aesthetic values may be best realized by continuing efforts, as implied by the Water Quality Act of 1965, toward enhancement of water quality for all uses.

Unique or outstanding waters

Certain bodies of water in the United States merit special considerations in establishing water quality criteria and standards. Examples include Lake Tahoe, Crater Lake, portions of Biscayne Bay and other coastal and estuarine areas, rivers (including a number which may be designated as "scenic" or "wild" rivers under State or Federal law) reservoirs, and lakes—waters which by reason of clarity, color, scenic setting, or other characteristics provide aesthetic values of unique or special interest. The Subcommittee recommends that such special waters be identified and specific standards developed in each case to protect their unique values.

recreation

Observations on recreation values

Recreation uses of water in the United States have historically occupied an inferior position in practice and law relative to other uses.

Where maintenance of recreation quality water placed no significant burden on other water users, recreation has customarily been considered an appropriate use. If other uses degraded quality below recreation quality, the recreation user has usually been expected to seek alternative waters, a task constantly rendered more difficult by rapidly expanding urbanization and industrialization.

In a number of Western States, recreation does not appear in the roster of "beneficial uses" enumerated by statute. The recognition of recreation as a benefit and a purpose of water resource development is a matter of recent history for such Federal agencies as the Corps of Engineers, the Bureau of Reclamation, and the Soil Conservation Service.

The reasons for these priorities in the uses of water are found in the transition from an agrarian to an industrial and urban society. Now the Nation faces a new order of social problems including, for the first time in history, a serious concern for the creative uses of the increasing amounts of leisure available to our people. Today there is a growing realization that recreation is a full partner in water use; one that, with associated services, represents a multimillion dollar industry with substantial prospects for future growth as well as an important source of psychic and physical relaxation.

Outdoor recreation is a preferred form of leisure activity for increasing millions of Americans; water and shorelines serve as a focal point for many preferred forms of outdoor recreation. Quantity, location, and accessibility as well as quality of water are prime factors in satisfying outdoor recreation demands. These facts are set forth in "Outdoor Recreation for America," the 1962 report of the Outdoor Recreation Resources Review Commission (ORRRC), and are confirmed by subsequent surveys of outdoor recreation activities and demands carried out by the Bureau of Outdoor Recreation (BOR), Department of the Interior.

One of the major findings and pervasive themes of the ORRRC report was that most people seeking outdoor recreation (90 percent of all Americans) seek it associated with water—to sit by, to walk alongside, to swim and to fish in, and to boat on.

Based on a 1960 survey, ORRRC found—for example—that swimming was second among outdoor recreation activities and was likely to be the most popular by the turn of the century. Boating and fishing were among the top 10 activities. Walking, camping, picnicking, and hiking—also high on the user preference list—are more attractive, higher quality experiences near clean water.

A 1965 survey by the Bureau of the Census, Department of Commerce, for BOR indicates that present and anticipated increases in all water-related activities far surpass ORRRC projections.

BOR's 1965 survey found—for example—that the popularity of swimming, now second only to "walking for pleasure," is increasing so fast that it is expected to be the number one outdoor activity by 1980 and continue to hold that place in 2000.

Expressed in other terms, BOR found that outdoor swimming "participation occasions" increased 44 percent between 1960 and 1965 (while the population of individuals 12 years old and older increased 8 percent). Between 1965 and 1980, BOR expects that swimming will increase 72 percent (while population is expected to increase 29 percent), and between 1965 and 2000, 207 percent (while population is expected to increase 76 percent).

Expressed in terms of individuals, rather than "occasions," BOR's 1965 survey found that 49 percent of the population (12 years old and older) went swimming outdoors that year, an increase of 15 percent since 1960. Comparable figures for some other water-related activities:

Fishing—30 percent of population participated, an increase of 12 percent since 1960.

Boating (other than canoeing and sailing)—24 percent, an increase of 18 percent.

This intimate connection between water and recreation suggests the need for coordination of outdoor recreation planning programs and water resources planning programs. Under the Land and Water Conservation Fund Act of 1965, and the Water Quality Act of 1965, the States are required to prepare comprehensive long-range plans for meeting the outdoor recreation needs of their people, and for the management of water quality on interstate waters, respectively. State and Federal water quality officials should draw upon statewide outdoor recreation plans (and the nationwide outdoor recreation plan now being prepared by the Bureau of Outdoor Recreation) for guidance in assessing recreation needs, and in developing and applying standards and criteria to waters under their jurisdictions. Similar coordination should be effective between water quality and comprehensive water resources planning programs now underway or planned for river basins throughout the country.

The Subcommittee emphasizes that the management of water resources to enhance recreational opportunities requires more than the maintenance of water quality. In addition to quantity, location, and accessibility of water, management for recreation may involve seasonal and even daily water level regulation during seasons and hours of peak use.

Recreation activities for which criteria are recommended

The Subcommittee has been asked to recommend criteria for water to be used for recreation.

In draft materials prepared for consideration by the Subcommittee, and in much of the available literature, water quality criteria for recreation concentrate on the protection of the health and safety of the recreation user.

It is the Subcommittee's conviction that water quality management programs for recreation should include criteria to—

(a) provide for and enhance general recreation use of surface waters;

(b) enhance recreation value of waters designated for recreation use; and

(c) provide special protection for the recreation user where significant body contact with water is involved.

Criteria for these purposes are set forth in succeeding sections.

Criteria for general recreational use of surface waters

The Subcommittee has concluded for reasons set forth below that it is necessary to recommend criteria for general recreation use of surface waters *without reference to specific designation of recreation as a water use.*

Considerations related to the recreation user

Recommendation: Surface waters should be suitable for use in "secondary contact" recreation—activities not involving significant risks of ingestion—without reference to official designation of recreation as a water use. For this purpose, in addition to aesthetic criteria, surface waters should be maintained in a condition to minimize potential health hazards by utilizing fecal coliform criteria. In the absence of local

epidemiological experience, the Subcommittee recommends an average not exceeding 2,000 fecal coliforms per 100 ml and a maximum of 4,000 per 100 ml, except in specified mixing zones adjacent to outfalls.

This level of fecal coliforms could be expected when concentrations of viral and other pathogens in receiving waters have been reduced to less than infectious levels for casual water contact by humans, with the risk considered to be one-tenth that for primary contact recreation (see criteria for primary contact recreation on p. 12). Further research will be necessary to arrive at precise criteria for secondary contact recreation activities.

This recommendation is intended to provide for the enjoyment, in relative safety, of uses customarily described as "secondary contact recreation," including boating, fishing, and limited contact with water incident to shoreline activities. Swimming, wading by children, and other activities usually referred to as "primary contact recreation" are not adequately provided for by this recommendation.

The recommendation recognizes the undeniable attraction of water to human beings: water has value, and is used, for a variety of recreational activities without regard to specific management for or designation of these uses.

In the Subcommittee's opinion, public policy and water quality criteria should provide for these values and uses as a normal and desirable management objective on surface waters of the United States.

The Subcommittee notes certain qualifications in its recommendation. There are, depending on local conditions, waters—typically below points of discharge and before mixing—where recreational uses should be discouraged, or in certain cases prohibited. (The Subcommittee assumes that zones for mixing are limited, and are specified and defined in water quality programs.) Quite apart from water quality, physical hazards—such as intensive navigation use—may make recreation use undesirable. If the Subcommittee's recommendation is accepted, an additional burden will be placed upon public agencies to develop positive programs to discourage recreation use where such use is clearly inadvisable.

Time is a factor in the Subcommittee's recommendation. The Subcommittee assumes that plans and programs for implementation of standards prepared by the States will set forth schedules for accomplishment of water quality criteria for various uses including secondary contact recreation uses.

The burden of the Subcommittee's finding is that surface waters—wherever there are people—have recreational potential, are likely to be used for recreation even if grossly polluted, and provide increased recreation value as quality improves. Thus both protecting the public health and enhancement of water quality for human satisfaction support the Subcommittee's recommendation. As in the case of aesthetic value, demands on water for recreation are likely to be most intense in urban areas, where suitable quality is most difficult to achieve.

The Subcommittee emphasizes that this recommendation is a suggested minimum requirement. Many of the most-sought-after forms of water recreation as described in user preference studies by the Bureau of Outdoor Recreation—swimming and "going to the beach," water skiing, surfing—call for water of significantly lower microbiological content than recommended here. Thus, while realization of secondary contact recreation water would involve a substantial upgrading of the quality of significant portions of surface waters, the minimum level suggested here still constitutes a severe limitation on the potential recreation value of surface waters. The Act of Congress under which these criteria are being developed specifies that one of its purposes is to enhance the value of the Nation's water resources. The Subcommittee emphasizes strongly that continuing improvement beyond the minimum levels specified for aesthetics in this section will add to the recreation value of surface waters.

In addition to criteria to permit safe public enjoyment of secondary contact recreation, the Subcommittee has concluded that a companion recommendation is necessary to provide for recreation based on utilization of fishes and other aquatic or water-related species as a general use of surface waters.

Recommendation: Surface waters, with specific and limited exceptions, should be of such quality as to provide for the enjoyment of recreation activities based upon the utilization of fishes, waterfowl and other forms of life, without reference to official designation of use. The Subcommittee recommends by reference criteria developed by the National Technical Advisory Subcommittee on Fish, Other Aquatic Life, and Wildlife for guidance relative to various species and waters.

Recreation based on utilization of aquatic and water-related animals is, in number of participants, a major recreation use of surface waters. The Subcommittee suggests that the maintenance and production of fish and wildlife utilized for recreation purposes must be assumed to be an objective of management of surface waters for general recreation use.

As in the preceding section, exceptions should be confined to specific mixing zones adjacent to outfalls.

The 1965 survey by the Bureau of the Census reported that over 42 million Americans engaged in recreational fishing—not counting children under 12 years of age. Over 1½ million hunted waterfowl. Recreation based upon taking of mollusks and crustaceans is significant, although data on use are not available. (Mollusks and crustaceans, in varying degrees, tend to concentrate certain pollutants beyond concentrations in water. Note is made of this fact in a succeeding recommendation.)

Another Subcommittee has been asked to recommend criteria for fish and wildlife. The recommendation in this section is made to underscore the nearly universal value and appeal of surface waters for recreation based on these life forms, and to recommend that these forms of recreation be provided for as a general recreation use of surface waters.

The Subcommittee realizes that optimum conditions for fish and wildlife are not attainable in all surface waters, even with the recommended exceptions for mixing zones. Significant recreation opportunities based on fish and wildlife may, however, be provided by less than optimum conditions, and these recreation values may be expected to increase as conditions are improved under careful management.

The use of specific waters for recreation based upon fish and wildlife may be undesirable for a number of reasons, including potential conflicts among recreation activities. Limitations on the recreational values of waters capable of providing recreational fishing and hunting under practical management for these purposes should not, however, be imposed by water quality.

The effect of the Subcommittee's recommendation is that recreation based upon utilization of fishes, other aquatic life forms, and waterfowl is logically assumed to be an objective of the management of surface waters. Criteria which fail to provide for these recreation activities constitute a limitation on recreation uses, except where such use is inappropriate for reasons other than water quality.

A significant part of fishing, hunting, and similar activities is consumption of the species involved. Water quality management should protect this use by controlling taste, odor, and safeness for consumption of harvestable species. It is the position of the Subcommittee that the recreation harvester of aquatic life is entitled to the same protection afforded the commercial producer and consumer.

Recommendation: Species available for harvest by recreation users should be fit for human consumption. In areas where taking of mollusks is a recreational activity, the criteria shall be guided by the U.S. Public Health Service manual "Sanitation of Shellfish Growing Areas," 1965 revision.

Criteria for the enhancement of recreation value of waters designated for recreation uses other than primary contact recreation

The preceding recommendations on criteria for general recreational use of surface waters note that regardless of whether or not such use is encouraged, people are drawn to and make use of water for a variety of recreation activities, and suggest criteria in recognition of this fact.

The recommendations in this section are intended to apply where recreation is a designated use for water quality management purposes (but not in cases where primary contact recreation is involved).

Water quality managers and recreation-supplying agencies share the opportunity and obligation to seek high quality in waters designated for recreational use and especially so in waters associated with public or private areas and facilities provided for recreation uses.

Water suitable for primary contact recreation uses is a desirable goal on all waters designated for recreation use. Criteria for primary contact use (set forth in a succeeding recommendation) should be applied wherever feasible and should be approached as closely as possible wherever recreation is a designated water use—especially where recreation use is encouraged by facilities such as boat launching ramps, campgrounds, fishing access points, and shoreline trails. Where wading and dabbling by children is a customary use in these areas, primary contact criteria should apply.

Where primary contact criteria can be applied, health hazards are minimized and the full range of recreation opportunities assured.

Aesthetic criteria apply, of course, to waters designated for recreation use. In addition, the Subcommittee recommends fecal coliform criteria designed to enhance and protect recreation use.

This recommendation is intended to establish microbiological criteria for "secondary contact" recreation activities on waters designated for recreation use. It is more stringent than the recommendation providing for secondary contact recreation on surface waters generally.

Recommendation: In waters designated for recreation uses other than primary contact recreation, the Subcommittee recommends that the fecal coliform content, as determined by either multiple-tube fermentation or membrane filter techniques, should not exceed a log mean of 1,000/100 ml, nor equal or exceed 2,000/100 ml in more than 10 percent of the samples.

Additional reductions of microbiological content will serve to further protect public health and enhance and encourage recreation enjoyment.

The Subcommittee recommends further that optimum conditions for recreation based upon fish, other aquatic forms, and water-related wildlife be assumed to be an objective of management of waters designated for recreation use.

Recommendation: In waters designated for recreation use, optimum conditions for recreation based upon utilization of fish, other aquatic life, and wildlife should apply, with specific and limited exceptions. The Subcommittee endorses by reference criteria for these purposes recommended by the National Technical Advisory Subcommittee on Fish, Other Aquatic Life, and Wildlife.

The Subcommittee has noted earlier its judgment that fishing, certain forms of hunting, and other recreation activities based upon fish and wildlife should be considered as a general recreation use of surface waters, with specific and limited exceptions.

It follows that, where recreation is a designated water use calling for special quality management efforts, optimum conditions for the species which provide these forms of recreation—as recommended by the National Technical Advisory Subcommittee on Fish, Other Aquatic Life, and Wildlife—should be assumed to be a management objective.

The Subcommittee notes that, even in major water areas designated for recreation use, water used for mixing adjacent to outfalls may fall below optimum conditions in specific and limited areas. The Subcommittee also notes that certain water-related recreation activities at a given site may conflict during certain seasons and times. The limitations on recreation use should not, however, be imposed by water quality.

Criteria for primary contact recreation

On the basis of microbiological criteria, water quality managers customarily divide water recreation users into two groups: those engaged in primary contact recreation and those engaged in secondary contact recreation.

The Subcommittee has provided for secondary contact recreation in earlier recommendations and will not deal with criteria for the purpose in this section.

The Subcommittee defines primary contact recreation as activities in which there is prolonged and intimate contact with the water involving considerable risk of ingesting water in quantities sufficient to pose a significant health hazard. Examples are wading and dabbling by children, swimming, diving, water skiing, and surfing. (Secondary contact sports include those in which contact with the water is either incidental or accidental and the probability of ingesting appreciable quantities of water is minimal.)

While similarities in water contact involved in trout or surf fishing and wading and dabbling by children seem to call for their inclusion in the same category, there are significant differences. Children are more likely to ingest water and may be more susceptible to pathogens in water. In this light, it would seem wise to set a goal of criteria for the protection of primary contact recreation for most waters adjacent to organized recreational areas such as picnicking areas and camping grounds customarily used by children.

The establishment of special criteria (e.g., public health requirements) necessary for the protection of the primary contact recreation user has been a major problem for the Subcommittee. Moreover, in recommending specific water quality criteria for this purpose the Subcommittee is faced with a sharp dilemma—that of balancing reasonable safeguards for the public health and physical well-being against possible undue restrictions on the availability of waters for contact recreation. The problem is further complicated by the inadequacy of studies correlating epidemiological data on water-borne diseases with degrees of pollution in recreational waters.

Two factors, microbiological contamination and pH, are so intimately associated with the health and physical well-being of the primary contact recreation user that they should be considered in management of waters for use for these purposes. While the inclusion of pH might be questioned, the Subcommittee believes its relation to eye irritations and subsequent infections justifies its consideration (see appendix at end of this section). None would question the necessity of including microbiological criteria in a "must" category, thus leaving only the question of what indicators and what limits should apply.

In attempting to resolve the safety versus unnecessary restriction dilemma, the Subcommittee considered at length the selection of most useful indicators of contamination. The ideal solution might be in the continuous and instantaneous determination of pathogens. However, time factors, multiplicity, and complexity of tests, economics of equipment, and other materials, and manpower requirements rule out use of pathogens as criteria for general application. The optimum solution then becomes one of monitoring an indicator organism.

The feces and urine of warmblooded animals are the most significant potential sources of waterborne pathogens capable of infecting man. Man has contracted cholera, typhoid, leptospirosis, schistosomiasis, and other diseases, with water as the vector, where the source of contamination was traced to animals. Time lapse and magnitude of contamination are critical factors in the degree of hazard. The problem now becomes one of selecting an appropriate indicator and numerical limits that will indicate contamination by excreta of warmblooded animals.

The use of total coliforms as an indicator has a long history, most recently through counts on membrane filters. While the total coliforms count may be a satisfactory indicator in certain respects, the Subcommittee believes that the variable correlation of total coliform content with contamination by excreta suggests that coliforms are not a satisfactory indicator of the possible presence of pathogens in recreational waters.

The portion of the total coliforms in water that are of fecal origin may range from less than 1 percent to more than 90 percent. At the 1 percent level, a limit of 1,000/100 ml total coliforms would constitute an undue limitation on availability of water for contact recreation. At the 90 percent level, a limit of 1,000/100 ml would constitute a threat to the health of the contact recreation user. Thus, total coliform criteria are not adequate for determining suitability of waters for use for contact recreation.

Fecal streptococci in combination with total coliforms are being used in sanitary evaluation. Selection of techniques to be applied and the interpretation of results are in a state of flux and uncertainty. Problems include the unresolved question of whether or not all types of fecal streptococci found in warmblooded animals are revealed by the tests, the fact that appreciable numbers of streptococci from other sources (plants and insects) yield positive test results, and added time and manpower requirements for monitoring agencies. Fecal streptococci should not be used as primary criteria, but are useful as a supplement to fecal coliforms where more precise determination of sources of contamination is necessary.

It is the Subcommittee's opinion that of the groups or organisms commonly employed in evaluating sanitary conditions in surface waters fecal coliform is by far the best choice for use in criteria for contact recreation. Two facts will demonstrate that fecal coliforms are superior indicators of recent contamination with feces of warmblooded animals. Approximately 95 percent of the total coliform organisms in the feces of both birds and mammals yield positive fecal coliform tests. A similar portion of the total coliform organisms in samples of uncontaminated soils and plant materials yield negative fecal coliform tests. It is important to note that use of fecal coliforms as an indicator does not add to the complexity or expense of monitoring.

There is an urgent need for research to refine correlations of various indicator organisms, including fecal coliforms, to water-borne disease. The Subcommittee feels that the Public Health Service's three epidemiological studies on bathing water quality and health are the only base available for setting criteria. These studies were far from definitive and were conducted before the acceptance of the fecal coliform as a more realistic measure of a health hazard. The studies at the Great Lakes (Mich.) and the Inland River (Ohio) showed an epidemiologically detectable health effect at levels of 2,300–2,400 coliforms per 100 ml. Later work on the stretch of the Ohio River where the study had been done indicated that the fecal coliforms represented 18 percent of the total coliforms. This would indicate that detectable health effects may occur at a fecal coliform level of about 400 per 100 ml; a factor of safety would indicate that the water quality should be better than that which would cause a health effect.

The Santee project correlated the prevalence of virus with fecal coliform concentrations following sewage treatment. Virus levels following secondary treatment can be expected to be 1 PFU per milliliter with a ratio of one virus particle per 10,000 fecal coliforms. A bathing water with 400 fecal coliforms per 100 ml could be expected to have 0.02 virus particles per 100 ml (one virus particle per 5,000 ml.)

On these bases, the committee recommends the following.

Recommendation: Fecal coliforms should be used as the indicator organism for evaluating the microbiological suitability of recreation waters. As determined by multiple-tube fermentation or membrane filter procedures and based on a minimum of not less than five samples taken over not more than a 30-day period, the fecal coliform content of primary contact recreation waters shall not exceed a log mean of 200/100 ml, nor shall more than 10 percent of total samples during any 30-day period exceed 400/100 ml.

It is the position of the Subcommittee that, if neither excessive health hazards nor undue restriction on availability of recreational waters are to occur, sanitary criteria for water contact recreation should reflect the foregoing recommendations. The Subcommittee recognizes that localized bacterial standards may be justified, if based on sufficient experience, sanitary surveys, or other control and monitoring systems. For greatest value, such actions should include a thorough analysis of the sources of contamination and the degree of threat of pathogens from specific sources.

The Subcommittee notes that fecal discharges from vessels are individually a small contribution to contamination and may not be reflected in bacterial sampling, but represent a rather direct health hazard and must be controlled in or near primary contact recreational areas.

In addition to sanitary criteria, the Subcommittee recommends criteria on pH for primary contact recreation waters. While the Subcommittee recognizes that many waters (marine, naturally alkaline, or acidic fresh waters) cause eye irritation, the relation of pH to eye irritation justifies inclusion of pH criteria to enhance recreation enjoyment where pH can be controlled.

In the light of its coordinate effect, the buffering capacity should be considered in criteria to prevent eye irritation.

The lacrimal fluid of the human eye has a normal pH of approximately 7.4 and a very high buffering capacity, due primarily to the presence of buffering agents of the complex organic type. As is true of many organic buffering agents, those of the lacrimal fluid are able to maintain the pH within a very narrow range until their buffering capacity is exhausted. When the lacrimal fluid, through exhaustion of its buffering capacity, is unable to adjust the immediate contact layer of a fluid to a pH of 7.4, eye irritation results. A deviation of no more than 0.1 unit from the normal pH of the eye may result in discomfort. Appreciable deviation will cause severe pain (see appendix at the end of this section).

Recommendation: In primary contact recreation waters, the pH should be within the range of 6.5-8.3 except when due to natural causes and in no case shall be less than 5.0 nor more than 9.0. When the pH is less than 6.5 or more than 8.3, discharge of substances which would increase the buffering capacity of the water should be limited.

There are additional criteria the Subcommittee considers to be desirable but not mandatory. Among these are criteria for clarity and temperature. Clarity in recreational waters is highly desirable from the standpoint of visual appeal, recreational enjoyment, and safety. Variation in natural conditions makes it difficult to set absolute criteria for this factor. However, turbidity attributable to human activity should be controlled in recreation waters where feasible in the light of natural conditions.

Recommendation: For primary contact recreation waters, clarity should be such that a Secchi disc is visible at a minimum depth of 4 feet. In "learn to swim" areas the clarity should be such that a Secchi disc on the bottom is visible. In diving areas the clarity shall equal the minimum required by safety standards, depending on the height of the diving platform or board.

The Subcommittee is cognizant that recommendations on clarity may have more value for planners of primary recreation areas than for water quality administrators.

Temperature is another factor which may be important to recreation enjoyment. In some localities and at certain times, elevation of temperature may be desirable (to lengthen a recreation season, for instance), but in most cases total recreation values (including particularly recreational fishing) are more likely to be reduced than enlarged by excessive temperature elevation. Except in cases where temperature elevations for primary contact recreation are justified, the Subcommittee suggests a stringent restriction on permissible temperature rises.

Excessively high temperatures may lessen the pleasure of some water contact sports, as well as be damaging to biota. Moreover, high temperatures limit the dissipation of body heat and may, through elevation of the deep body temperature, produce serious physiological disturbances. It has been determined that a person swimming expends energy at the rate of approximately 500 calories per hour. This is about five times the rate when sitting still and about twice the rate when walking. This energy must be dissipated to the environment to avoid a rise in the deep body temperature. When conduction is the principal means of heat transfer from the body and exposure to the environmental conditions is prolonged, 32.2 C (90 F) is the approximate limit for persons expending minimal energy. Since most swimmers utilize energy at a moderate rate, the maximum water temperature that will not induce undesirable physiological effects after prolonged exposure must be less than 32.2 C (90 F). Experience with military personnel exposed to warm water continously for several hours indicates that 30 C (85 F) is a safe maximum limit.

Limited exposure to water warmer than 30 C (85 F) can be tolerated for short periods of time without causing undesirable physiological effects. In fact, some people get particular enjoyment from bathing in water from hot springs. However, these are special circumstances and persons bathing in such water usually limit their exposure to short periods of time and do not engage in moderate exercise such as swimming for prolonged periods.

Recommendation: In primary contact recreation waters, except where caused by natural conditions, maximum water temperature should not exceed 30 C (85 F).

Other aspects of water quality for the primary contact recreation user, including those associated with mental satisfaction rather than health or physical well-being, can be met by adherence to recommendations for realization of aesthetic values and enhancement of recreation enjoyment.

Recreation criteria for marine waters

The Subcommittee has considered the advisability of establishing separate criteria for marine and estuarine waters. While some studies would seem to indicate that nothing short of actual ingestion of particulate fecal matter constitutes a threat to the recreation user in marine waters, the Subcommittee does not feel that information now available justifies separate criteria.

Several additional arguments favoring more lenient microbiological criteria in marine waters have been advanced, but upon careful consideration these have been rejected by the Subcommittee as not being sufficient justification for relaxation of the criteria.

It is frequently stated that salt water is less palatable than fresh water and when accidentally taken into the mouth is ejected rather than ingested, thus materially lessening the chance of intake of water-borne pathogens. However, salt water is not so unpalatable that it is automatically ejected. This is particularly true in the case of children where the sophistications of adults have not developed.

Another argument posed in favor of the lessened threat of pathogens from fecal contamination in marine waters is the bactericidal properties of these waters. However, the bactericidal properties of marine waters are weak; their effectiveness in providing a safety factor is questionable. Moreover, if marine waters were bactericidal, the presence of indicator organisms would indicate very recent fecal contamination, which, in the absence of demonstrated selective bactericidal effect on pathogens, might suggest a greater threat to health than comparable concentrations of indicator organisms in fresh water. One might cite the outbreaks of infectious hepatitis traced to marine sources as a further refutation of the protection afforded by bactericidal properties of marine waters.

In view of the foregoing, the Subcommittee would suggest, as a general practice, application of a single set of criteria for recreation in fresh, estuarine, and marine waters. Given the lack of definitive data, reasonable latitude for criteria in marine waters should be provided in specific instances where acceptable monitoring and observation support other criteria.

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The role of some physico-chemical properties of water as causative agents of eye irritation of swimmers

by Eric W. Mood, M.P.H.

appendix

An important consideration of the physico-chemical characteristics of water used for recreation purposes involves those properties that may cause eye irritation to bathers and swimmers. Water is a foreign environment to the human eye. Under certain conditions, water may be very irritating to the eyes of most swimmers and bathers, but under other conditions it may be non-irritating to all but a few.

Some knowledge about the characteristics of water that generally is irritating to the eyes of swimmers has been developed through research efforts of ophthalmologists and others, many of whom were interested in the preparation of ophthalmic solutions. These researchers assumed that an ideal non-irritating solution would have similar physico-chemical properties as tears. Therefore, studies were undertaken initially to determine the chemical composition of lacrimal fluid, particularly of the following: (1) hydrogen-ion concentration or pH, (2) buffer capacity, and (3) tonicity.

Early studies of the hydrogen-ion concentration of tears developed values ranging from 6.3 to 8.6. Diligent efforts by Hind and Goyan (*1*, *2*) yielded more precise data. They found that lacrimal fluid has a pH of approximately 7.4. This result is not unexpected as the pH of human blood normally is found to range from 7.4 to 7.5.

Correlated with the hydrogen-ion concentration is buffer capacity of the fluid. A solution of low buffer capacity can have its pH level changed easily, but a solution with a high buffer capacity may not have the hydrogen-ion concentration easily or appreciably altered. Analyses for the chemical constituents of tears denoted the presence of carbonic acid, weak organic acids and proteins (*3*). These elements allow lacrimal fluid to neutralize both weakly acidic and weakly basic solutions to the approximate pH of the lacrimal fluid. It has been demonstrated that tears have the capacity to bring the pH of an unbuffered solution from as low as 3.5 or as high as 10.5, to within tolerable limits in a very short time (*3*).

If the chemical constituents of the solution in contact with the eye are such as to resist the buffering action of the lacrimal fluid and the pH of the solution in direct contact with the eye is 0.1 or more units of pH higher or lower than pH-7.4, a pain response may be elicited.

In addition to the factors concerning hydrogen-ion concentration and buffer capacity, the tonicity of the fluid in contact with the eye is an important consideration to minimize irritation or pain response. Lacrimal fluid is isotonic (i.e., having the same osmotic pressure) with blood and has a tonicity equivalent to that of a 0.9-percent sodium chloride solution. Early studies by Hind and Goyan (*1*) showed that a sodium chloride equivalent range of 0.5 percent to 2.0 percent concentration was well tolerated. Later, Riegelmann, Vaughan and Okumoto (*5*), and Riegelmann and Vaughan (*4*) suggested that the range be narrowed to the equivalence of between 0.7 percent to 1.5 percent sodium chloride.

Tonicity of water used for recreation will be important in reducing or preventing eye irritation only in those cases where there is prolonged exposure of the eye to water. The usual type of recreational bathing and swimming which most people engage in does not usually involve prolonged exposure of the eye to water. Hence, tonicity of recreation waters is of much less importance than the hydrogen-ion concentration and the buffer capacity in preventing or reducing eye irritation to bathers and swimmers.

An ideal water that would be non-irritating to the majority of bathers would be one that is relatively unbuffered and has a sodium chloride equivalent of 0.9 percent and a pH of 7.4. Since the ideal can seldom, if ever, be achieved, alternate values are necessary. While the lacrimal fluid can adjust the pH of an unbuffered solution from as low as 3.5 or as high as 10.5 to within tolerable limits within a short time, these limits of pH have no practical value as unbuffered water is not found in nature under usual conditions. Almost all natural waters have some buffer capacity. Therefore, to minimize eye irritation to bathers, it seems desirable to suggest that for natural waters with low buffer capacity, the pH range be between 5.0 and 9.0. Since most natural waters have more than a low buffer capacity, a more desirable range of pH would be 6.5 to 8.3.

In summary, when water quality standards are proposed for swimming, bathing, and other similar uses, consideration should be given to those physico-chemical properties that may cause or contribute to eye irritation. Of principal importance is the hydrogen-ion concentration with codependence upon the buffer capacity of the water. Ideally, the pH of water should be approximately the same as the pH of lacrimal fluid which is about 7.4 for most people. Since the lacrimal fluid has a high buffering capacity, a range of pH values from 6.5 to 8.3 can be tolerated under average conditions. If the recreation water is relatively free of dissolved solids and has a very low buffer capacity, pH values from 5.0 to 9.0 should be acceptable. However, for recreation water having a pH less than 6.5 or greater than 8.3, waste discharge standards should include prohibition against releases that will increase the buffer capacity of the receiving waters and yet maintain the pH below 6.5 or greater than 8.3. Tonicity standards do not seem to have any practical value.

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Section II

public water supplies

introduction

THE NATIONAL Technical Advisory Subcommittee on Public Water Supplies has found it necessary to make some rather arbitrary decisions in order to proceed with its task of developing raw water quality criteria for public water supplies. Because public water supplies commonly involve processing of the raw water to improve its quality before distributing it to consumers, and because treatment processes exist which can, at a price, convert almost any water including sea water and grossly polluted fresh water into a potable product, it is necessary to consider the type of treatment in any discussion of raw water quality criteria for public water supplies.

We have adopted as the considered treatment the most common processes in use in this country in their simplest form for the treatment of surface waters for public use. This may include coagulation (less than about 50 ppm alum, ferric sulfate, or copperas with alkali addition as necessary but without coagulant aids or activated carbon), sedimentation (6 hours or less), rapid sand filtration (3 gal/sq ft/min or less) and disinfection with chlorine (without consideration to concentration or form of chlorine residual). A wide variety of modifications of this basic treatment process are in use for removing various impurities or altering quality characteristics, but we have arbitrarily excluded these modifications in our deliberations because of the difficulty in deciding where to stop in considering the many modifications and elaborations of the basic process.

Definitions

We have listed two types of criteria defined as follows:

(a) *Permissible criteria.*—Those characteristics and concentrations of substances in raw surface waters which will allow the production of a safe, clear, potable, aesthetically pleasing, and acceptable public water supply which meets the limits of Drinking Water Standards (*10*) after treatment. This treatment may include, but will not include more than, the processes described above.

(b) *Desirable criteria.*—Those characteristics and concentrations of substances in the raw surface waters which represent high-quality water in all respects for use as public water supplies. Water meeting these criteria can be treated in the defined plants with greater factors of safety or at less cost than is possible with waters meeting permissible criteria.

Several words used in the table and in the text require explanation in order to convey the Subcommittee's intent:

Narrative.—The presence of this word in the table indicates that the Subcommittee could not arrive at a single numerical value which would be applicable throughout the country for all conditions. Where this word appears, the reader is directed to the appropriate explanatory text.

Absent.—The most sensitive analytical procedure in Standard Methods (*9*) (or other approved procedure) does not show the presence of the subject constituent.

Virtually absent.—This terminology implies that the substance is present in very low concentrations and is used where the substance is not objectionable in these barely detectable concentrations.

discussion

THE SUBCOMMITTEE recognizes that surface waters are used for public water supply without treatment other than disinfection. Such waters at the point of withdrawal should meet Drinking Water Standards (*10*) in all respects other than bacterial quality.

It should be emphasized that many raw water sources which do not meet these permissible criteria have been and are being used to provide satisfactory public water supplies by suitable additions to and elaboration of the treatment processes defined above. In some instances, however, the water delivered to the customer is of marginal quality. Also the finished water is much more likely to become unsatisfactory if treatment plant irregularities occur. It is recognized that most of the surface water treatment plants providing water for domestic use in the United States are relatively small (*7*) and without sophisticated technical controls. Marginal quality characteristics, therefore, assume considerable importance to the managers of plants treating such supplies. This is the importance of the factors of safety mentioned in the definition of "desirable criteria". However, managers of all supplies would welcome improved raw water quality.

This Subcommittee believes that the criteria set forth herein can be used in setting standards of raw water quality only with a substantial amount of understanding and discretion. To a considerable extent this is related to the very great regional variations in water quality entirely aside from manmade pollution. In addition, human occupance and activity have inevitable effects on water quality. These facts make it difficult and sometimes impossible to develop uniform numerical criteria suitable for national application.

The criteria selected by the Subcommittee are listed in the table and discussed in the numbered paragraphs cited in the table. The paragraphs also include some rationale of the basis for the criteria. The fact that a substance is not included in these criteria does not imply that its presence is innocuous. It would be quite impracticable to prepare a compendium of all toxic, deleterious, or otherwise unwelcome agents that may enter a surface water supply.

Sampling

Sampling should be of such frequency and of such variety (time of day, season, temperature, river stage or flow, location, depth) as to properly describe the body of water designated for public water supply. Sampling should also be conducted in full cognizance of findings of the sanitary survery. Judgment should be exercised as to the relative desirability of frequent sampling at one point, such as the raw water intake, as compared to less frequent sampling at numerous locations, such as is required for stream profiles or cross sections.

It is clearly not possible to apply these criteria solely as maximum single sample values. The criteria should not be exceeded over substantial portions of time. If they are exceeded, efforts should be made to determine the cause, and corrective measures undertaken.

Analytical methods

The criteria are based upon those analytical methods described in Standard Methods for the Examination of Water and Wastewater (*9*) or upon methods acceptable to water pollution control agencies.

TABLE II–1. Surface Water Criteria for Public Water Supplies

Constituent or characteristic	Permissible criteria	Desirable criteria	Paragraph
Physical:			
Color (color units)	75	<10	1
Odor	Narrative	Virtually absent	2
Temperature *	do	Narrative	3
Turbidity	do	Virtually absent	4
Microbiological:			
Coliform organisms	10,000/100 ml [1]	<100/100 ml [1]	5
Fecal coliforms	2,000/100 ml [1]	<20/100 ml [1]	5
Inorganic chemicals:	(mg/l)	(mg/l)	
Alkalinity	Narrative	Narrative	6
Ammonia	0.5 (as N)	<0.01	7
Arsenic *	0.05	Absent	8
Barium *	1.0	do	8
Boron *	1.0	do	9
Cadmium *	0.01	do	8
Chloride *	250	<25	8
Chromium,* hexavalent	0.05	Absent	8
Copper *	1.0	Virtually absent	8
Dissolved oxygen	≥4 (monthly mean) ≥3 (individual sample)	Near saturation	10
Fluoride *	Narrative	Narrative	11
Hardness *	do	do	12
Iron (filterable)	0.3	Virtually absent	8
Lead *	0.05	Absent	8
Manganese * (filterable)	0.05	do	8
Nitrates plus nitrites *	10 (as N)	Virtually absent	13
pH (range)	6.0–8.5	Narrative	14
Phosphorus *	Narrative	do	15
Selenium *	0.01	Absent	8
Silver *	0.05	do	8
Sulfate *	250	<50	8
Total dissolved solids * (filterable residue).	500	<200	16
Uranyl ion *	5	Absent	17
Zinc *	5	Virtually absent	8
Organic chemicals:			
Carbon chloroform extract * (CCE)	0.15	<0.04	18
Cyanide *	0.20	Absent	8
Methylene blue active substances *	0.5	Virtually absent	19
Oil and grease *	Virtually absent	Absent	20
Pesticides:			
Aldrin *	0.017	do	21
Chlordane *	0.003	do	21
DDT *	0.042	do	21
Dieldrin *	0.017	do	21
Endrin *	0.001	do	21
Heptachlor *	0.018	do	21
Heptachlor epoxide *	0.018	do	21
Lindane *	0.056	do	21
Methoxychlor *	0.035	do	21
Organic phosphates plus carbamates.*	0.1 [2]	do	21
Toxaphene *	0.005	do	8
Herbicides:			
2,4-D plus 2,4,5-T, plus 2,4,5-TP *	0.1	do	21
Phenols *	0.001	do	8
Radioactivity:	(pc/l)	(pc/l)	
Gross beta *	1,000	<100	8
Radium-226 *	3	<1	8
Strontium-90 *	10	<2	8

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* The defined treatment process has little effect on this constituent.

[1] Microbiological limits are monthly arithmetic averages based upon an adequate number of samples. Total coliform limit may be relaxed if fecal coliform concentration does not exceed the specified limit.

[2] As parathion in cholinesterase inhibition. It may be necessary to resort to even lower concentrations for some compounds or mixtures. See par. 21.

Paragraph 1: Color

A limit of 75 color units (platinum-cobalt standard) has been recommended to permit the defined plant to produce water meeting Drinking Water Standards (*10*) with moderate dosages of coagulant chemicals. At optimum pH the dosage usually required is linearly related to the color of the raw water, and higher color of the type commonly associated with swamp drainage and similar nonindustrial sources can be removed by increasing the coagulant dose. These criteria do not apply to colors resulting from dyes and some other industrial and processing sources which cannot be measured by the platinum-cobalt standard. Such colors should not be present in concentrations which cannot be removed by the defined method of treatment.

Paragraph 2: Odor

The effectiveness of the defined method of treatment in removing odorous materials from water is highly variable depending on the nature of the material causing the odor. For this reason, it has not been feasible to specify any permissible criterion in terms of threshold odor number. The raw water should not have objectionable odor. Any odors present should be removable by the defined treatment. It is desirable that odor be virtually absent.

Paragraph 3: Temperature

Surface water temperatures vary with geographical location and climatic conditions. Consequently no fixed criteria are feasible. However, any of the following conditions are considered to detract (sometimes seriously) from raw water quality for public water supply use:

(1) Water temperature higher than 85 F;

(2) More than 5 F water temperature increase in excess of that caused by ambient conditions;

(3) More than 1 F hourly temperature variation over that caused by ambient conditions;

(4) Any water temperature change which adversely affects the biota, taste, and odor, or the chemistry of the water;

(5) Any water temperature variation or change which adversely affects water treatment plant operation (for example, speed of chemical reactions, sedimentation basin hydraulics, filter wash water requirements, etc.);

(6) Any water temperature change that decreases the acceptance of the water for cooling and drinking purposes.

Paragraph 4: Turbidity

Turbidity in water must be readily removable by coagulation, sedimentation, and filtration; must not be present in quantities (either by weight or volume) that will overload the water treatment plant facilities; and must not cause unreasonable treatment costs. In addition, turbidity in water must not be frequently changing and varying in characteristics or in quantity to the extent that such changes cause upset in water treatment plant processing.

Customary methods for measuring and reporting turbidity do not adequately measure those characteristics harmful to public water supply and water treatment processing. A water with 30 Jackson turbidity units may coagulate more rapidly than one with 5 or 10 units. Similarly water with 30 Jackson turbidity units sometimes may be more difficult to coagulate than water with 100 units. Sometimes clay added to very low turbidity water will improve coagulation. Therefore, it has not been possible to establish a turbidity criterion in terms of Jackson turbidity units. Neither can a turbidity criterion be expressed in terms of mg/l "undissolved solids" or "nonfilterable solids." The type of plankton, clay, or earth particles, their size and electrical charges, are far more determining factors than the Jackson turbidity units. Nevertheless, it must be clearly recognized that too much turbidity or frequently changing turbidity is damaging to public water supply.

The criterion for too much turbidity in water must relate to the capacity of the water treatment plant to remove turbidity adequately and continuously at reasonable cost. Water treatment plants are designed to remove the kind and quantity of turbidity to be expected in each water supply source. Therefore, any increase in turbidity and any fluctuating turbidity load over that normal to a water must be considered in excess of that permissible.

Paragraph 5: Coliform and Fecal Coliform Organisms

Bacteria have been used as indicators of sanitary quality of water since 1880 when *B. coli* and similar organisms were shown to be normal inhabitants of fecal discharges. The coliform group as presently recognized by Drinking Water Standards (*10*) is defined in Standard Methods for the Examination of Water and Wastewater (*9*). This group includes organisms that vary in biochemical and serologic characteristics and in their natural sources and habitats; i.e., feces, soil, water, vegetation, etc.

Because the sanitary significance of the various members of the coliform group derives from their natural sources, differentiation of fecal from non-fecal organisms is important to evaluate raw water quality (*5*). Fecal coliforms are characteristically inhabitants of warmblooded animal intestines. Members of other coliform subgroups may be found in soil, on plants and insects, in old sewage, and in waters polluted some time in the past.

The objective of using the coliform group as an indicator of the sanitary quality of water is to evaluate the disease-producing potential of the water. To estimate the probability of pathogens being contributed from feces, the coliform and fecal coliform content must be quantified.

In relation to raw water sources, the following suggestions are offered to help resolve some of the difficulties of data interpretation.

Fecal coliform organisms may be considered indicators of recent fecal pollution. It is necessary to consider all fecal coliform organisms as indicative of dangerous contamination. Moreover, no satisfactory method is currently available for differentiating between fecal organisms of human and animal origin.

In the absence of fecal coliform organisms, the presence of other coliform group organisms may be the result of less recent fecal pollution, soil runoff water, or, infrequently, fecal pollution containing only those organisms.

In general, the presence of fecal coliform organisms indicates recent and possibly dangerous pollution. The presence of other coliform organisms suggests less recent pollution or contributions from other sources of non-fecal origin.

In the past the coliform test has been the principal criterion of suitability of raw water sources for public water supply. The increase in chlorination of sewage treatment plant effluents, distorts this criterion by reducing coliform concentrations without removing many other substances which the defined water treatment plant is not well equipped to remove. It is essential that raw water sources be judged as to suitability by other measures and criteria than coliform organism concentrations.

The defined water treatment plant is considered capable of producing water meeting Drinking Water Standards (*10*) bacteriological criteria from these limits. The difference between the suggested concentration of 10,000 coliforms per 100 ml and the erstwhile figure of 5,000 per 100 ml is justified by the difference between the Phelps Index and the MPN. The Subcommittee suggests these numbers and the additional consideration of fecal coliforms in order to provide more realistic parameters in full recognition of modern knowledge and not as a means of sanctioning increased bacterial pollution of waters destined for public water supply use.

Paragraph 6: Alkalinity

Alkalinity in water should be sufficient to enable floc formation during coagulation, must not be high enough to cause physiological distress in humans, and must be proper for a chemically balanced water (neither corrosive nor incrusting). A criterion for minimum and maximum alkalinity in public water supply is related to the relative amounts of bicarbonates, carbonates, and hydroxide ions causing the alkalinity; and also to the pH, filterable (dissolved) solids, and calcium content. Because the permissible criterion for filterable solids is 500 mg/l and the pH range is 6.0 to 8.5, alkalinity should not be less than about 30 mg/l.

The criterion for maximum alkalinity cannot be expressed in calcium carbonate equivalents as determined from 0.02N H_2SO_4 titration because of the interrelationships stated above. However, alkalinity values higher than about 400 mg/l to 500 mg/l would be too high for public water supply use. Within the range of 30 mg/l to 500 mg/l, the alkalinity criterion should be that value which is normal to the natural water and which from experience is satisfactory for public water supply use. Frequent variations from normal values are detrimental to public water supply processing control.

Paragraph 7: Ammonia

Ammonia is a significant pollutant in raw water for public water supplies because its reactions with chlorine result in compounds with markedly less disinfecting efficiency than free chlorine. In addition, it is frequently an indicator of recent sewage pollution.

In the early days of waste treatment, the oxidation of ammonia to nitrates was one of the major objectives of waste treatment, but with the development of the BOD test, this objective became neglected. Greater attention to the design and operation of waste treatment plants for the oxidation of ammonia and organic nitrogen is needed to minimize the concentration of pollution forms in these receiving waters.

Paragraph 8: Arsenic, Barium, Cadmium, Chromium (Hexavalent), Copper, Chloride, Cyanide, Iron, Lead, Manganese, Phenols, Selenium, Silver, Sulfate, Zinc, and Radioactive Substances

The significance of these substances as contaminants of drinking water is discussed in Drinking Water Standards (*10*). The permissible criteria in this report are those included in Drinking Water Standards. With the possible exception of iron and in some instances copper and zinc, the defined treatment plant does little or nothing to remove these substances.

Paragraph 9: Boron

Boron is found in the natural ground and surface waters in some areas of the United States, notably in the Western States where as much as 5 to 15 mg/l are encountered. However, extensive data on boron in both well and surface waters in North America show that the amount of boron normally encountered is less than 1 mg/l. The ingestion of large amounts of boron can affect the central nervous system and protracted ingestion may result in a clinical syndrome known as borism.

Boron is an essential element to plant growth but is toxic to many plants at levels as low as 1 mg/l. The Public Health Service has established a limit of 1 mg/l which provides a good factor of safety physiologically and also considers the domestic use of water for home gardening.

Paragraph 10: Dissolved Oxygen

Criteria for dissolved oxygen are included, not because the substance is of appreciable significance in water treatment or in finished water, but because of its use as an indicator of pollution by organic wastes. It is intended for application to freeflowing streams and not to lakes or reservoirs in which supplies may be taken from below the thermocline.

Paragraph 11: Fluoride

The Subcommittee recognizes the potential beneficial effects of fluoride ion in domestic water supplies but recommends no "desirable" concentration since any value less than that recommended for the permissible limit would be acceptable from the point of view of a water pollution control program. Rapid fluctuations in raw-water fluoride ion levels would create objectionable operating problems for communities supplementing raw-water fluoride concentrations. The permissible criterion is the upper limit of the recommended range in Drinking Water Standards (*10*).

Annual average of Maximum daily air temperatures[1] F:	*Recommended Limit mg/l*
50.0 to 53.7	1.7
53.8 to 58.3	1.5
58.4 to 63.8	1.3
63.9 to 70.6	1.2
70.7 to 79.2	1.0
79.3 to 90.5	0.8

[1] Based on temperature data obtained for a minimum of 5 years.

Paragraph 12: Hardness

A singular criterion for the maximum hardness in public water supply is not possible. Hardness in water is largely the result of geological formations with which the water comes in contact. Public acceptance of hardness varies from community to community. Consumer sensitivity to objectionable hardness is related to the hardness with which he has become accustomed. Consumer acceptance of hardness may also be tempered by economic necessity.

Hardness should not be present in concentrations that will cause excessive soap consumption, or which will cause objectionable scale in heating vessels and pipes. In addition, varying water hardness is objectionable to both domestic and industrial water consumers. With varying hardness, the soap required for laundry, the effect on manufactured products, and the damage to process equipment (such as boilers and cooling coils) cannot be anticipated and compensated without facilities which are not available to most water users. A water hardness criterion must relate to the hardness which is normal to the supply and exclude hardness additions which will cause variations.

A criterion for objectionable hardness must be tailored to fit the requirements of each community. Hardness more than 300–500 mg/l as $CaCO_3$ is excessive for public water supply. Many consumers will object to water harder than 150 mg/l. In other communities, the criterion for maximum water hardness is considerably less than 150 mg/l. A moderately hard water is sometimes defined as having hardness between 60 to 120 mg/l.

Paragraph 13: Nitrate plus Nitrite

A limit of 10 mg/l(N) of nitrate ion plus nitrite ion will be recommended by Drinking Water Standards (*10*). Because the nitrite ion is the substance actually responsible for causing methemoglobinemia, a combined limit on the two ions is more significant than a limit on nitrates only.

Paragraph 14: pH

Most unpolluted waters have pH values within the range recommended as a permissible criterion. Any pH value within this range is acceptable for public water supply. The further selection of a specific pH value within this range as a desirable criterion cannot be made.

Paragraph 15: Phosphorus

The Subcommittee has considered establishing criteria on phosphorus concentrations but has not been able to establish any generally acceptable limit because of the complexity of the problem. The purpose of such a limit would be twofold:

(a) To avoid problems associated with algae and other aquatic plants, and
(b) To avoid coagulation problems due particularly to complex phosphates.

Phosphorus is an essential element for aquatic life as well as for all forms of life and has been considered the most readily controllable nutrient in efforts to limit the development of objectionable plant growths. Evidence indicates that high phosphorus concentrations are associated with the eutrophication of waters that is manifest in unpleasant algal or other aquatic plant growths when other growth-promoting factors are favorable; that aquatic plant problems develop in reservoirs or other standing waters at phosphorus values lower than those critical in flowing streams; that reservoirs and other standing waters will collect phosphates from influent streams and store a portion of these within the consolidated sediments; that phosphorus concentrations critical to noxious plant growths will vary with other water quality characteristics, producing such growths in one geographical area but not in another.

Because the ratio of total phosphorus to that form of phosphorus readily available for plant growth is constantly changing and will range from two to 17 times or greater, it is desirable to establish limits on the total phosphorus rather than the portion that may be available for immediate plant use. Most relatively uncontaminated lake districts are known to have surface waters that contain 10 to 30 μg/l total phosphorus as P; in some waters that are not obviously polluted, higher values may occur (*4*). Data collected by the Federal Water Pollution Control Administration, Division of Pollution Surveillance, indicate that total phosphorus concentrations exceeded 50 μg/l (P) at 48 percent of the stations sampled across the Nation (*6*). Some potable surface water supplies now exceed 200 μg/l (P) without experiencing notable problems due to aquatic growths. Fifty micrograms per liter of total phosphorus (as P) would probably restrict noxious aquatic plant growths in flowing waters and in some standing waters. Some lakes, however, would experience algal nuisances at and below this level.

Critical phosphorus concentrations will vary with other water quality characteristics. Turbidity and other factors in many of the Nation's waters negates the algal-producing effects of high phosphorus concentrations. When waters are detained in a lake or reservoir, the resultant phosphorus concentration is reduced to some extent over that in influent streams by precipitation or uptake by organisms and subsequent deposition in fecal pellets or dead organism bodies. See the report of the Subcommittee for Fish, Other Aquatic Life, and Wildlife, and the section on Plant Nutrients and Nuisance Organisms for a more complete discussion of phosphorus associations with the enrichment problem.

At concentrations of complex phosphates of the order of 100 μg/l, difficulties with coagulation are experienced.

Paragraph 16: Total Dissolved Solids (Filterable Residue)

Drinking Water Standards (*10*) recommend that total dissolved solids not exceed 500 mg/l where other more suitable supplies are available. It is noted, however, that some streams contain total dissolved solids in excess of 500 mg/l. For example, the Colorado River at the point of withdrawal by the Metropolitan Water District of Southern California has a total dissolved solids concentration up to 700 mg/l.

High total dissolved solids are objectionable because of physiological effects, mineral taste, or economic effect. High concentrations of mineral salts, particularly sulfates and chlorides, are associated with corrosion damage in water systems. Regarding taste, on the basis of limited research work underway in California, limits somewhat higher than 500 mg/l are probably acceptable to consumers of domestic water supplies. It is likely that levels set with relation to economic effects are controlling for this parameter.

Increases in total dissolved solids from those normal to the natural stream are undesirable and may be detrimental.

It is recommended that the permissible value for total dissolved solids be set at 500 mg/l in view of the above evaluation. Further, it is recommended that research work be sponsored to obtain more information on total dissolved solids in water relating to physiological effects, consumer attitudes toward taste, and economic considerations.

Paragraph 17: Uranyl Ion

The standard for uranyl ion (UO_2^{++}) is established on the basis of its chemical properties rather than on the basis of its being a radioactive material. It is being added to Drinking Water Standards (*10*). Uranyl ion is of concern in drinking water because of possible damage to the kidneys. The threshold level of taste and the appearance of color due to uranyl ion occur at about 10 mg/l which is much less than the safe limit of ingestion of this ion insofar as adverse physiological effects are concerned.

The Public Health Service adopted the figure of 5 mg/l which is one-half the limit based on taste and color and, therefore, there is a considerable factor of safety in the adoption of 5 mg/l.

Paragraph 18: Carbon Chloroform Extract (CCE)

A limit of 0.2 mg/l carbon chloroform extract in drinking water is recommended in the Drinking Water Standards "as a safeguard against the intrusion of excessive amounts of potentially toxic material into water" (*10, 3*). Although the analytical procedure then in use leaves much to be desired from the standpoint of simplicity, reproducibility, and interpretation, it was the best available at that time. The analytical procedure has been improved since then and the newer technique (*1, 2*) gives substantially higher results than the one originally used. The defined method of treatment generally removes very little of the CCE present in the raw water. In many instances there is an increase during treatment. Whether this is real or apparent is not known.

The permissible criterion of 0.15 mg/l recommended is based on use of the procedure cited in Drinking Water Standards (*10*). We do not as yet have sufficient information on which to base a recommended limit using the lower flow rates and sample volumes of the newer procedure. When this information is available, a change in the criterion is advisable. This limit is generally attainable where vigorous efforts at pollution control are carried out.

Paragraph 19: Methylene Blue Active Substances

This is an operationally more precise name for substances discussed in Drinking Water Standards (*10*) as alkyl benzene sulfonate. The permissible criterion is the same as the limit recommended in those standards. Those standards have been revised to reflect this change in nomenclature.

Paragraph 20: Oil and Grease

It is very important that water for public water supply be free of oil and grease. The difficulty of obtaining representative samples of these materials from water makes it virtually impossible to express criteria in numerical units. Since even very small quantities of oil and grease may cause troublesome taste and odor problems, the Subcommittee desires that none of this material be present in public water supplies. An additional problem attributable to these agents is the unsightly scumlines on water treatment basin walls, swimming pools, and other containers.

Paragraph 21: Pesticides and Herbicides

Consideration was given by the Subcommittee to three groups of pesticides: the more common chlorinated hydrocarbons, herbicides, and the cholinesterase-inhibiting group which include the organic phosphorus types and the carbamates. The permissible levels are based upon recommendations of the Public Health Service Advisory Committee on Use of the PHS Drinking Water Standards. These values were derived for that Committee by an expert group of toxicologists as those levels which, if ingested over extensive periods, could not cause harmful or adverse physiological changes in man. In the case of aldrin, heptachlor, chlordane, and parathion, the Committee adopted even lower than physiologically safe levels; namely, amounts which, if present, can be detected by their taste and odor. It should be noted that this National Technical Advisory Subcommittee on Public Water Supplies is not a group of toxicological experts. Hence, the promulgation of additional criteria by the Public Health Service would also be accommodated by this Subcommittee, tempered—as was done above—by its experience and judgment in the area of water treatment, as, for example, in public acceptance of organoleptic properties.

The limit for the cholinergic pesticides is established relative to parathion and is expressed as 0.1 mg/l parathion equivalent. This equivalence is the ratio that a given pesticide of this group has to parathion as unity in its cholinesterase inhibiting properties. This makes it incumbent upon an administrator of this limit to determine the pesticide involved and to obtain expert toxicological opinion on its parathion equivalence. Nearly all the organophosphorus compounds and the cholinergic carbamates have high acute toxicity to mammals and some have even higher toxicity to fish. Ingestion of small quantities of these compounds over long time periods causes damage to mammalian central nervous systems. Many organophosphorus pesticides hydrolyze rapidly in the environment to harmless or less harmful products. The hazards from the chlorinated hydrocarbon pesticides in water results from both direct effects, because they tend to persist in their original form over long periods, and indirect effects because they may be concentrated biologically in man's food chain. The values which were selected by the Public Health Service as limits for this group of pesticides are, however, set with substantial safety factors insofar as they adversely affect the human body. Generally, fish are more sensitive to this group of pesticides and, therefore, may serve as a rough method for determining when the chlorinated hydrocarbon pesticides content of water is approaching a danger level. See the report of the Fish, Other Aquatic Life, and Wildlife Subcommittee for pesticide limits relative to maintaining healthy and productive aquatic life.

It should be noted that limits for pesticides and herbicides have been set with relation only to human intake directly from a related domestic water supply. The consequence of higher and possibly objectionable concentrations in fish available to be eaten by man due to biological concentration is considered not within the scope of the charge to this Subcommittee.

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Section III

fish, other aquatic life, and wildlife

letter from the chairman

THE MEMBERSHIP of the National Technical Advisory Subcommittee on Water Quality Criteria for Fish, Other Aquatic Life, and Wildlife represents training and experience in several phases of freshwater, marine and wildlife ecology, physiology, and toxicology. The task of this Subcommittee is to describe, insofar as possible, under present knowledge: (1) the environmental requirements of aquatic life and wildlife, (2) the environmental concentrations of potential toxicants that are not harmful under long-term exposure, and (3) to suggest indirect methods for determining safe concentrations through bioassays and application factors. Because present knowledge of environmental requirements is incomplete and information on safe concentrations of toxicants is nonexistent for most organisms, the recommendations for water quality criteria of necessity are incomplete, tentative, and subject to change as additional information becomes available. In the determination of these criteria, the Subcommittee has utilized the broad knowledge, the many years of experience, and the understanding and commonsense of the Subcommittee members.

In order to expedite this task, the Subcommittee was divided into three groups: one for freshwater organisms; one for marine and estuarine organisms; and a third for wildlife.

Six task forces were set up in each of the first two groups. Each of these task forces was assigned certain environmental factors to review present knowledge and determine environmental conditions essential for the survival, growth, reproduction, general well-being, and production of a desired crop of aquatic organisms. Members assigned to each task force were experts on that particular subject or had wide experience with the factors or materials in question. They were selected with this in mind so that the whole subject could be covered most effectively. The composite report thus prepared was reviewed by the full Subcommittee and approved on October 31 and November 1, 1967, in Washington, D.C.

CLARENCE M. TARZWELL,
Chairman.

introduction

DURING the course of geologic time, organisms which were able to adapt so they were better fitted to live under existing environmental conditions were the ones which survived and now form the biota. Geologic change is a slow process and biota developed which were adapted not only to the physical and chemical but also to the biological factors of the environment. The environmental factors to which organisms adapted through the evolutionary process are now their environmental requirements. Therefore, any relatively rapid change in these conditions can be detrimental or even disastrous. Because the biota is the result of long evolutionary processes during which delicate balances were established, a change in conditions or in a portion of the biota can have far reaching effects.

Man has now attained the ability to alter drastically his environment and that of other organisms. Many of his activities already have impaired seriously his own environment and that of other living things. Water pollution engineering works and other changes that modify the aquatic environment rank high in causing detrimental effects.

Water pollutants may be harmful through alterations in natural environmental conditions (such as temperature, dissolved oxygen, pH, carbonates, etc.), through physiological and other changes due to the addition of toxicants, or through both. Thus, in determining the effects of pollutants we must consider environmental, physiological, and accumulative effects.

Substances in suspension and solution, whether solid, liquid, or gas, largely determine the quality of the water. Aquatic organisms are affected not only directly by these materials, but also indirectly through their effects on other forms of aquatic life which comprise their food, competitors, and predators. Hence, the determination of water quality requirements for aquatic life is a very involved task. The problem is further complicated by the fact that different species and different developmental or life stages of the same or different species may differ widely in their sensitivity or tolerance to different materials, to ranges in environmental conditions, and to the cumulative synergistic and antagonistic effects of toxicants.

In determining water quality requirements for aquatic life and wildlife, it is essential to recognize that there are not only acute and chronic toxic levels but also tolerable, favorable, and essential levels of dissolved materials. Lethal, tolerable, and favorable levels and conditions may be ascertained by: (1) determining the environmental factors and concentrations of materials which are favorable in natural waters; (2) determining by laboratory studies the relative sensitivity of organisms to various environmental factors, and ranges which are tolerable and favorable; (3) determining by means of different bioassay studies the behavioral, physiological, and other responses of organisms to potential toxicants and concentrations of these materials which are not harmful under continuous exposure; and (4) testing laboratory findings in the field to determine their adequacy for the protection of aquatic and wildlife resources.

In approaching this problem of protecting our aquatic and wildlife resources, it must also be realized that: (1) certain natural complexes of dissolved materials to which aquatic organisms have become adapted are favorable whereas other concentrations or compositions may not be; (2) unnatural materials added by man can be unfavorable; (3) altering the amounts of substances normally found in the environment can be harmful; (4) toxicity is a quantitative term—any material becomes toxic when its concentration exceeds certain levels. It is essential, also, to realize that requirements must be maintained throughout periods of low water, maximum discharge, maximum temperature, minimum DO, variations in pH, turbidity, salinity, etc. Further, it should be understood that: (1) unfavorable conditions which may be resisted for long periods by adults may be entirely unfavorable for the survival of the species; (2) conditions need to be unfavorable for only a few hours to eliminate a population or group of species; and (3) levels of environmental factors and concentrations of toxicants that appear to cause no harm during a few hours of exposure may be intolerable for extended periods or for recurring short-term exposures.

In defining water quality requirements for aquatic life and wildlife, it is necessary to define the extreme upper and lower limits of the various environmental factors as well as the optimum values. These extremes are outer limits and constitute the minimum objectives to be obtained in the improvement of waters for aquatic life. It is not the intention of the Subcommittee that such levels are to be considered as satisfactory. Further, it is stressed that waters of higher quality should not be degraded towards approximation of the extremes. For example, the dissolved oxygen content of water should be near saturation for best production. The lower limits for oxygen indicated in the report, therefore, represents the objective to be obtained in the improvement of water, and not the level to which good waters may be lowered.

It is essential that the various recommendations be considered in context with the body of the report, taking due consideration of the variability of local conditions and native biota.

Within the United States there are great variations in environmental conditions and in the flora and fauna. The environmental requirements of the biota are different not only for different regions but for different portions of the same region. Overlying these differences are seasonal changes and daily variations that have become essential factors in the environment. Ideally, therefore, water quality criteria for aquatic life and wildlife should take into consideration local variations in requirements, seasonal changes, and daily variations. They should be national in scope. They should be applicable to streams of various size and character, to all types of lakes, to reservoirs, estuaries, and coastal waters.

It is obvious that more research is needed on the character, conditions, and interrelations in fresh water, marine, and estuarine ecosystems which are subjected to degradation or alteration as well as on the physiological requirements and tolerances of the various species involved in these different ecosystems. This need must be satisfied for the establishing of sound criteria to maintain and preserve aquatic resources and to permit the most economical and productive use of these resources by man.

Further, water quality requirements must be expressed so as to allow for environmental modifications where such modifications are justifiable and deemed to be in the public interest.

All these factors have been considered in developing the following recommended water quality requirements for aquatic life.

It is the purpose of this document to define the water quality requirements which must be met to insure a favorable environment for fish, other aquatic life, and wildlife. This report will do this by identifying those aspects of water quality that are most important in the light of current knowledge and quantifying them where possible. Where quantification is not yet possible, narrative guidelines will be offered. There is no doubt that the water quality requirements contained herein must be reviewed periodically and updated in the light of additional and improved scientific data. The recommendations given in this report are considered to be satisfactory for aquatic life. In all instances where natural conditions fall outside the recommended ranges, this environment may be marginal and should not be changed in such a way as to make it more unfavorable.

zones of passage

ANY BARRIER to migration and the free movement of the aquatic biota can be harmful in a number of ways. Such barriers block the spawning migration of anadromous and catadromus species. Many resident species make local migrations for spawning and other purposes and any barrier can be detrimental to their continued existence. The natural tidal movement in estuaries and downstream movement of planktonic organisms and of aquatic invertebrates in flowing fresh waters are important factors in the re-population of areas and the general economy of the water. Any chemical or thermal barrier destroys this valuable source of food and creates unfavorable conditions below or above it.

It is essential that adequate passageways be provided at all times for the movement or drift of the biota. Water quality criteria favorable to the aquatic community must be maintained at all times in these passageways. It is recognized, however, that certain areas of mixing are unavoidable. These create harmfully polluted areas and for this reason it is essential that they be limited in width and length and be provided only for mixing. The passage zone must provide favorable conditions and must be in a continuous stretch bordered by the same bank for a considerable distance to allow safe and adequate passage up and down the stream, reservoir, lake, or estuary for free-floating and drift organisms.

The width of the zone and the volume of flow in it will depend on the character and size of the stream or estuary. Area, depth, and volume of flow must be sufficient to provide a usable and desirable passageway for fish and other aquatic organisms. Further, the cross-sectional area and volume of flow in the passageway will largely determine the percentage of survival of drift organisms. Therefore, the passageway should contain preferably 75 percent of the cross-sectional area and/or volume of flow of the stream or estuary. It is evident that where there are several mixing areas close together they should all be on the same side so the passageway is continuous. Concentrations of waste materials in passageways should meet the requirements for the water.

The shape and size of mixing areas will vary with the location, size, character, and use of the receiving water and should be established by proper administrative authority. From the standpoint of the welfare of the aquatic life resource, however, such areas should be as small as possible and be provided for mixing only. Mixing should be accomplished as quickly as possible through the use of devices which insure that the waste is mixed with the allocated dilution water in the smallest possible area. At the border of this area, the water quality must meet the water quality requirements for that area. If, upon complete mixing with the available dilution water these requirements are not met, the waste must be pretreated so they will be met. For the protection of aquatic life resources, mixing areas must not be used for, or considered as, a substitute for waste treatment, or as an extension of, or substitute for, a waste treatment facility.

summary and key criteria

RECOMMENDATIONS given below are considered to be satisfactory for aquatic life. In all instances where natural conditions fall outside the recommended ranges, these conditions may be marginal and should not be changed in such a way as to make them more unfavorable.

Freshwater organisms

Dissolved Materials

(1) Dissolved materials that are relatively innocuous; i.e., their harmful effect is due to osmotic effects at high concentrations, should not be increased by more than one-third of the concentration that is characteristic of the natural condition of the subject water. In no instance should the concentration of total dissolved materials exceed 50 milliosmoles (the equivalent of 1500 mg/l NaCl).

(2) Dissolved materials that are harmful in relatively low concentrations are discussed in the section "Toxicity."

pH, Alkalinity, Acidity

(1) No highly dissociated materials should be added in quantities sufficient to lower the pH below 6.0 or to raise the pH above 9.0.

(2) To protect the carbonate system and thus the productivity of the water, acid should not be added in sufficient quantity to lower the total alkalinity to less than 20 mg/l.

(3) The addition of weakly dissociated acids and alkalies should be regulated in terms of their own toxicities as established by bioassay procedures.

Temperature

Warm Water Biota: To maintain a well-rounded population of warm-water fishes, the following restrictions on temperature extremes and temperature increases are recommended:

(1) During any month of the year heat should not be added to a stream in excess of the amount that will raise the temperature of the water (at the expected minimum daily flow for that month) more than 5 F. In lakes, the temperature of the epilimnion in those areas where important organisms are most likely to be adversely affected should not be raised more than 3 F above that which existed before the addition of heat of artificial origin. The increase should be based on the monthly average of the maximum daily temperature. Unless a special study shows that a discharge

of a heated effluent into the hypolimnion will be desirable, such practice is not recommended and water for cooling should not be pumped from the hypolimnion to be discharged to the same body of water.

(2) The normal daily and seasonal temperature variations that were present before the addition of heat due to other than natural causes should be maintained.

(3) The recommended maximum temperatures that are not to be exceeded for various species of warm-water fish are given in table III-1.

Cold Water Biota: Because of the large number of trout and salmon waters which have been destroyed, made marginal, or nonproductive, remaining trout and salmon waters must be protected if this resource is to be preserved.

Inland trout streams, headwaters of salmon streams, trout and salmon lakes, and the hypolimnion of lakes and reservoirs containing salmonids and other cold water forms should not be warmed or used for cooling water. No heated effluents should be discharged in the vicinity of spawning areas.

For other types and reaches of cold-water streams, reservoirs and lakes, the following restrictions are recommended:

(1) During any month of the year heat should not be added to a stream in excess of the amount that will raise the temperature of the water more than 5 F (based on the minimum expected flow for that month). In lakes, the temperature of the epilimnion should not be raised more than 3 F by the addition of heat of artificial origin.

(2) The normal daily and seasonal temperature fluctuations that existed before the addition of heat due to other than natural causes should be maintained.

TABLE III–1

[Provisional maximum temperatures recommended as compatible with the well-being of various species of fish and their associated biota]

93 F: Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, and gizzard shad.
90 F: Growth of largemouth bass, drum, bluegill, and crappie.
84 F: Growth of pike, perch, walleye, smallmouth bass, and sauger.
80 F: Spawning and egg development of catfish, buffalo, threadfin shad, and gizzard shad.
75 F: Spawning and egg development of largemouth bass, white and yellow bass, and spotted bass.
68 F: Growth or migration routes of salmonids and for egg development of perch and smallmouth bass.
55 F: Spawning and egg development of salmon and trout (other than lake trout).
48 F: Spawning and egg development of lake trout, walleye, northern pike, sauger, and Atlantic salmon.

Note.—Recommended temperatures for other species, not listed above, may be established if and when necessary information becomes available.

(3) The recommended maximum temperatures that are not to be exceeded for various species of cold-water fish are given in table III–1.

Dissolved Oxygen

The following environmental conditions are considered essential for maintaining native populations of fish and other aquatic life.

(1) For a diversified warm-water biota, including game fish, DO concentration should be above 5 mg/l, assuming normal seasonal and daily variations are above this concentration. Under extreme conditions, however, they may range between 5 and 4 mg/l for short periods during any 24-hour period, provided that the water quality is favorable in all other respects. In stratified lakes, the DO requirements may not apply to the hypolimnion. In shallow unstratified lakes, they should apply to the entire circulation water mass.

These requirements should apply to all waters except administratively established mixing zones. In lakes, such zones must be restricted so as to limit the effect on the biota. In streams, there must be adequate and safe passageways for migrating forms. These must be extensive enough so that the majority of plankton and other drifting organisms are protected (see section on zones of passage).

(2) For the cold-water biota, it is desirable that DO concentrations be at or near saturation. This is especially important in spawning areas where DO levels must not be below 7 mg/l at any time. For good growth and the general well-being of trout, salmon, and their associated biota, DO concentrations should not be below 6 mg/l. Under extreme conditions, they may range between 6 and 5 mg/l for short periods provided the water quality is favorable in all other respects and normal daily and seasonal fluctuations occur. In large streams that have some stratification or that serve principally as migratory routes, DO levels may range between 4 and 5 mg/l for periods up to 6 hours, but should never be below 4 mg/l at any time or place.

(3) DO levels in the hypolimnion of oligotrophic small inland lakes and in large lakes should not be lowered below 6 mg/l at any time due to the addition of oxygen-demanding waste or other materials.

Carbon Dioxide

According to our present knowledge of the subject, it is recommended that the "free" carbon dioxide concentration should not exceed 25 mg/l.

Oil

Oil or petrochemicals should not be added in such quantities to the receiving waters that they will—

(1) produce a visible color film on the surface;
(2) impart an oily odor to the water or an oily or other noxious taste to fish and edible invertebrates;
(3) coat the banks and bottoms of the water course or taint any of the associated biota;
(4) become effective toxicants according to the criteria recommended in the "Toxicity" section.

Turbidity

(1) Turbidity in the receiving waters due to the discharge of wastes should not exceed 50 Jackson units in warm-water streams or 10 Jackson units in cold-water streams.

(2) There should be no discharge to warm-water lakes which would cause turbidities exceeding 25 Jackson units. The turbidity of cold-water or oligotrophic lakes should not exceed 10 units.

Settleable Materials

Since it is known that even minor deposits of settleable materials inhibit the growth of normal stream and lake flora, no such materials should be added to these waters in quantities that adversely affect the natural biota.

Color and Transparency

For effective photosynthetic production of oxygen, it is required that 10 percent of the incident light reach the bottom of any desired photosynthetic zone in which adequate dissolved oxygen concentrations are to be maintained.

Floating Materials

All floating materials of foreign origin should be excluded from streams and lakes.

Tainting Substance

All materials that will impart odor or taste to fish or edible invertebrates should be excluded from receiving waters at levels that produce tainting.

Radionuclides

(1) No radioactive materials should be present in natural waters as a consequence of the failure of an installation to exercise appropriate controls to minimize releases.

(2) No radionuclide or mixture of radionuclides should be present at concentrations greater than those specified by the USPHS Drinking Water Standards.

(3) The concentrations of radioactive materials present in fresh, estuarine, and marine waters should be less than those that would require restrictions on the use of organisms harvested from the area to meet the Radiation Protection Guides recommended by the Federal Radiation Council.

Plant Nutrients and Nuisance Growths

The Subcommittee wishes to stress that the concentrations set forth are suggested solely as guidelines and the maintenance of these may or may not prevent undesirable blooms. All the factors causing nuisance plant growth and the level of each which should not be exceeded are not known.

(1) In order to limit nuisance growths, the addition of all organic wastes such as sewage, food processing, cannery, and industrial wastes containing nutrients, vitamins, trace elements, and growth stimulants should be carefully controlled. Furthermore, it should be pointed out that the addition of sulfates or manganese oxide to a lake should be limited if iron is present in the hypolimnion as they may increase the quantity of available phosphorus.

(2) Nothing should be added that causes an increased zone of anaerobic decomposition of a lake or reservoir.

(3) The naturally occurring ratios and amounts of nitrogen (particularly NO_3 and NH_3) to total phosphorus should not be radically changed by the addition of materials. As a guideline, the concentration of total phosphorus should not be increased to levels exceeding 100µg/l in flowing streams or 50 µg/l where streams enter lakes or reservoirs.

(4) Because of our present limited knowledge of conditions promoting nuisance growth, we must have a biological monitoring program to determine the effectiveness of the control measures put into operation. A monitoring program can detect in their early stages the development of undesirable changes in amounts and kinds of rooted aquatics and the condition of algal growths. With periodic monitoring, such undesirable trends can be detected and corrected by more stringent regulation of added organics.

Toxic Substances

(1) **Substances of Unknown Toxicity:** All effluents containing foreign materials should be considered harmful and not permissible until bioassay tests have shown otherwise. It should be the obligation of the agency producing the effluent to demonstrate that it is harmless in the concentrations to be found in the receiving waters. All bioassays should be conducted strictly as recommended in the body of this report and the appropriate appli-

cation factor applied to determine the permissible concentration of toxicant.

(2) **Pesticides.**

(a) **Chlorinated hydrocarbons:** Any addition of chlorinated hydrocarbon insecticides is likely to cause damage to some desired organisms and should be avoided.

(b) **Other chemical pesticides:** Addition of other kinds of chemicals used as pesticides and herbicides can cause damage to desirable organisms and should be applied with utmost discretion and caution. Table III–5 (p. 62) lists the 48-hour TL_m values of a number of pesticides for various types of fresh water organisms. To provide reasonably safe concentrations of these materials in receiving waters, application factors ranging from 1/10 to 1/100 should be used with these values depending on the characteristic of the pesticide in question and used as specified in (4), below. Concentrations thus derived may be considered tentatively safe under the conditions specified.

(3) **Other Toxic Substances.**

(a) **ABS:** Concentration of continuous exposure to ABS should not exceed 1/7 of the 48-hour TL_m. A concentration as high as 1 mg/l may be tolerated occasionally for periods of time not exceeding 24 hours. ABS may increase the toxicity of other materials.

(b) **LAS:** The concentration of LAS should not exceed 0.2 mg/l or 1/7 of the 48-hour TL_m.

(4) **Application Factors:** Concentration of materials that are nonpersistant (that is, have a half-life of less than 96 hours) or have noncumulative effects after mixing with the receiving waters should not exceed 1/10 of the 96-hour TL_m value at any time or place. The 24-hour average of the concentration of these materials should not exceed 1/20 of the TL_m value after mixing. For other toxicants the concentrations should not exceed 1/20 and 1/100 of the TL_m value under the conditions described above. Where specific application factors have been determined, they will be used in all instances.

(5) **General Considerations.** When two or more toxic materials that have additive effects are present at the same time in the receiving water, some reduction is necessary in the permissible concentrations as derived from bioassays on individual substances or wastes. The amount of reduction required is a function of both the number of toxic materials present and their concentrations in respect to the derived permissible concentration. An appropriate means of assuring that the combined amounts of the several substances do not exceed a permissible concentration for the mixture is through the use of following relationship:

$$\left(\frac{C_a}{L_a}+\frac{C_b}{L_b}\;\cdots\;+\frac{C_n}{L_n}\leq 1\right)$$

Where C_a, C_b, . . . C_n are the measured concentrations of the several toxic materials in the water and L_a, L_b, . . . L_n are the respective permissible concentration limits derived for the materials on an individual basis. Should the sum of the several fractions exceed one, then a local restriction on the concentration of one or more of the substances is necessary.

Marine and estuarine organisms

Salinity

To protect estuarine organisms, no changes in channels, basin geometry, or freshwater influx should be made which would cause permanent changes in isohaline patterns of more than 10 percent of the naturally occurring variation.

Currents

Currents are important for transporting nutrients, larvae, and sedimentary materials for flushing and purifying wastes, and for maintaining patterns of scour and fill. To protect these functions, there should be no changes in basin geometry or freshwater inflow that will alter current patterns in such a way as to adversely affect existing biological and sedimentological situations.

pH

No materials that extend normal ranges of pH at any location by more than 0.1 pH unit should be introduced into salt water portions of tidal tributaries or coastal waters. At no time should the introduction of foreign materials cause the pH to be less than 6.7 nor greater than 8.5.

Temperature

In view of the requirements for the well-being and production of marine organisms, it is concluded that the discharge of any heated waste into any coastal or estuarine waters should be closely managed. Monthly means of the maximum daily temperatures recorded at the site in question and before the addition of any heat of artificial origin should not be raised by more than 4 F during the fall, winter, and spring (September through May), or by more than 1.5 F during the summer (June through August), North of Long Island and in the waters of the Pacific Northwest (north of California), summer limits apply July through September; and fall, winter, and spring limits apply October through June. The rate of temperature change should not exceed 1 F per hour except when due to natural phenomena.

Suggested temperatures are to prevail outside of established mixing zones as discussed in the section on zones of passage.

Dissolved Oxygen

Oxygen levels sufficient for the survival, growth, reproduction, general well-being, and production of a suitable crop must be maintained. The dissolved oxygen concentrations necessary to attain this objective in coastal waters, estuaries, and tidal tributaries are:

(1) Dissolved oxygen concentrations in surface coastal waters should be greater than 5.0 mg/l except when upwellings and other natural phenomena may cause this value to be depressed.

(2) Dissolved oxygen concentration in estuaries and tidal tributaries should not be less than 4.0 mg/l at any time or place except in naturally dystrophic waters or where natural conditions cause DO to be depressed.

Oil

No oil or petroleum products should be discharged into estuarine or coastal waters in quantities that: (1) Can be detected as a visible film, sheen, or by odor; (2) cause tainting of fish or edible invertebrates; (3) form an oil sludge deposit on the shores or bottom of the receiving body of water; (4) become effective toxicants according to the criteria recommended in the "Toxicity" section.

Turbidity

No effluent that may cause changes in turbidity or color should be allowed to enter estuarine or coastal waters unless it can be shown to have no deleterious effects on the aquatic biota.

Settleable and Floating Substances

No materials that contain settleable solids or substances that may precipitate out in quantities that adversely affect the biota should be introduced into coastal or estuarine waters. It is especially urgent that areas which serve as habitat or nursery grounds for commercially important species be protected from any impairment of natural conditions.

Tainting Substances

Substances that taint or produce off-flavors in fish and edible invertebrates should not be present in concentrations discernible by bioassay or organoleptic tests.

Radionuclides

The recommendations made for freshwater organisms apply to marine and estuarine organisms.

Plant Nutrients and Nuisance Organisms

(1) No changes should be made in the basin geometry, current structure, salinity, or temperature of the estuary until studies have shown that these changes will not adversely affect the biota or promote the increase of nuisance organisms.

(2) The artificial enrichment of the marine environment from all sources should not cause any major quantitative or qualitative alteration in the flora such as the production of persistant blooms of phytoplankton (whether toxic or not), dense growths of attached algae or higher aquatics, or any other sort of nuisance that can be attributed directly to nutrient excess or imbalance. Because these nutrients often are derived largely from drainage from land, special attention should be given to correct land management in river basins and shores of embayments to control unavoidable erosion.

(3) The naturally occurring atomic ratio of NO_3-N to PO_4-P in a body of water should be maintained. Similarly, the ratio of inorganic phosphorus (orthophosphate) to total phosphorus (the sum of inorganic phosphorus, dissolved organic phosphorus, and particulate phosphorus) should be maintained as it occurs naturally. Nutrient imbalances have been shown to cause a change in the natural diversity of desirable organisms and to reduce productivity.

Toxic Substances

(1) **Substances of Unknown Toxicity:** All effluents containing foreign materials should be considered harmful and not permissible until bioassay tests have shown otherwise. It should be the obligation of the agency producing the effluent to demonstrate that it is harmless in the concentrations that will be found in the receiving waters. All bioassays should be conducted strictly as recommended in the body of this report and the appropriate application factor applied to determine the permissible concentration of toxicant.

(2) **Pesticides for Which Limits Have Been Determined:** The pesticides are grouped according to their relative toxicity to shrimp. Criteria are based on the best estimates in the light of present knowledge and it is to be expected that acceptable levels of toxic materials may be changed as a result of future research.

Pesticide group A.—The following chemicals are acutely toxic at concentrations of 5 µg/l and less. On the assumption that $^{1}/_{100}$ of this level represents a reasonable application factor, it is recommended that environmental levels of these substances not be permitted to rise above 50 nanograms/l. This level is so low that these pesticides could not be applied directly in or near the marine habitat without danger of causing damage. The 48-hour TL_m is listed for each chemical in µg/l.

Organochloride pesticides

Aldrin	0.04	DDT	0.6
BHC	2.0	Dieldrin	0.3
Chlordane	2.0	Endosulfan	0.2
Endrin	0.2	Methoxychlor	4.0
Heptachlor	0.2	Perthane	3.0
Lindane	0.2	TDE	3.0
		Toxaphene	3.0

Organophosphorus pesticides

Coumaphos	2.0	Naled	3.0
Dursban	3.0	Parathion	1.0
Fenthion	0.03	Ronnel	5.0

Pesticide group B.—The following types of pesticide compounds are generally not acutely toxic at levels of 1.0 mg/l or less. It is recommended that an application factor of $^{1}/_{100}$ be used and in the absence of acute toxicity data that an environmental level of not more than 10 µg/l be permitted. An acute toxicity factor must be established for each specific chemical in this group to determine that it is not more toxic than related compounds as indicated above:

Arsenicals
Botanicals
Carbamates
2,4-D compounds
2,4,5-T compounds.
Phthalic acid compounds.
Triazine compounds.
Substituted urea compounds.

Other Pesticides.—Acute toxicity data are available for approximately 100 technical-grade pesticides in general use not listed in the above groups. These chemicals are either not likely to reach the marine environment or, if used as directed by the registered label, probably would not occur at levels toxic to marine biota. It is presumed that criteria established for these chemicals in fresh water will protect adequately the marine habitat. It should be emphasized that no unlisted chemical should be discharged into the estuary without preliminary bioassay tests.

(3) **Industrial and Other Toxic Wastes.**

(a) Safe concentrations of metals, ammonia, cyanide, and sulfide should be determined by the use of appropriate application factors to 96-hour TL_m values as determined by flow-through bioassays using dilution water that came from the receiving body. Test organisms should be local species or life stages of organisms of economic and ecologic importance which are the most sensitive to the waste in question. Application factors should be $^{1}/_{100}$ for metals, $^{1}/_{20}$ for ammonia, $^{1}/_{10}$ for cyanide, and $^{1}/_{20}$ for sulfide.

(b) Fluoride concentrations should not exceed those for drinking water.

(c) Permissible levels of detergents in fresh waters should also be applied to the marine and estuarine waters.

(d) Bacteriological criteria of estuarine waters utilized for shellfish cultivation and harvesting should conform with the standards as described in the National Shellfish Sanitation Program Manual of Operation. These standards provide that—

(*1*) examinations shall be conducted in accordance with the American Public Health Association recommended procedures for the examination of sea water and shellfish;

(*2*) there shall be no direct discharges of untreated sewage;

(*3*) samples of water for bacteriological examination to be collected under those conditions of time and tide which produce maximum concentration of bacteria;

(*4*) the coliform median MPN of the water does not exceed 70/100 ml, and not more than 10 percent of the samples ordinarily exceed an MPN of 230/100 ml for a five-tube decimal dilution test (or 330/100 ml, where the three-tube decimal dilution test is used) in those portions of the area most probably exposed to fecal contamination during the most unfavorable hydrographic and pollution conditions;

(*5*) the reliability of nearby waste treatment plants shall be considered in the approval of areas for direct harvesting.

(e) Wastes from tar, gas, coke, petrochemical, pulp and paper manufacturing, waterfront and boating activities, hospitals, marine laboratories and research installation wastes are all complex mixtures having great variability in character and toxicity. Due to this variability, safe levels must be determined at frequent intervals by flow-through bioassays of the individual effluents.

For those operations having persistent toxicants, an application factor of $^{1}/_{100}$ should be used while for those composed largely of unstable or biodegradable toxicants, an application factor of $^{1}/_{20}$ is tentatively suggested.

(4) **General Considerations.**—When two or more toxicants that have additive effects are present, they must be treated as suggested earlier under fresh water organisms.

Wildlife

Dissolved Oxygen

In addition to the DO requirements for aquatic organisms, the bottoms of areas used by wildfowl must be kept aerobic to suppress botulinus organisms.

pH

Aquatic plants of greatest value as food for waterfowl thrive best in waters with a summer pH range of 7.0 to 9.2.

Alkalinity

Waterfowl habitats, to be productive, should have a bicarbonate alkalinity between 30 and 130 mg/l. Fluctuations should be less than 50 mg/l from natural conditions.

Salinity

Salinity should be kept as close to natural conditions as possible. Fluctuations in salinity during any 24-hour period should be limited as follows:

Natural salinity:	*Variation permitted*
0 to 3.5‰	1‰
3.5 to 13.5‰	2‰
13.5 to 35.0‰	4‰

Light Penetration

Optimum light requirements for aquatic wildlife habitats should be at least 10 percent of incident light at the surface to a 6-foot depth; the tolerable limit should be 5 percent of the light at the surface to the same depth.

Settleable Substances

Settleable substances destroy the usefulness of aquatic bottoms for waterfowl. Settleable substances should be excluded from areas expected to support waterfowl.

Oil

Oil is an especially dangerous substance to waterfowl. Oil and petrochemicals must be excluded from both the surface and bottoms of any area used by waterfowl.

Toxic Substances

Toxic substances should be excluded from wildlife habitats to the degree that they affect the health and well-being of wildlife, either directly or through biological magnification. Special consideration must be given to keep edible wildlife safe for consumption by humans.

Disease

Offal from poultry houses, meatpacking plants, as well as other possible sources of disease organisms, must be excluded from areas supporting wildlife to guard against transmission of such diseases as botulism, fowl cholera, and aspergillosis.

General

Water quality suitable for fish and other aquatic organisms will be adequate for wildlife.

fresh water organisms

Dissolved materials

Water devoid of dissolved materials is intolerable in nature because pure water will not support aquatic life. Natural waters contain endless varieties of dissolved materials in concentrations that differ widely from one locality to another as well as from time to time. Many of these dissolved materials are essential for growth, reproduction, and the general well-being of aquatic organisms. The chlorides, carbonates, and silicates of sodium, potassium, calcium, and magnesium are generally the most common salts present. Traces of most other essential substances are also found.

Aquatic organisms live in different concentrations of dissolved substances but productivity declines as the concentrations move away from the optimum. Seldom, if ever, are the dissolved substances at the optimum concentrations as we know them. The range of tolerance may be relatively wide, but when the concentrations reach too low or too high a level, organisms degenerate and die. Different organisms vary in their optimum requirements as well as in their ability to live and thrive under variations from the optimum. Some organisms are equally at home in sea water and in fresh water. Other organisms will tolerate only one or the other.

Any of the substances necessary to aquatic organisms has a range of concentration that is both essential and tolerable. The tolerance levels for any one substance vary depending on the concentrations of other substances present. The presence of certain substances synergizes the effects of some materials but antagonizes the effects of others. Under optimal concentrations, the synergistic and antagonistic effects are in balance and relatively high concentrations can be tolerated without adverse effects.

Although several measures of dissolved materials are available, no measure in itself is adequate as an index of optimum concentration nor is any single measure adequate to express the range of tolerance. The biological effects depend on the concentrations of the individual solutes, some of which are tolerated in terms of grams per liter but others only in nanograms per liter. Some exert considerable osmotic pressure, but for others the osmotic effect is negligible. Some substances contribute greatly to conductivity, while others have little or no effect.

In general, the concentrations of dissolved materials in natural fresh waters are below the optimum for maximum productivity. In many instances, therefore, the addition of any of a large number of substances will be beneficial. In this way, many water courses have a capacity to absorb materials to advantage. But the addition of what may be considered beneficial substances must be controlled so that they will not exceed favorable limits.

The osmotic concentration of the body fluids of a fresh water animal is generally the maximum concentration of dissolved material that the animal will tolerate. In some animals, notably some of the fresh water mollusks, the body fluids have an osmotic concentration as low as 50 milliosmoles (the equivalent of about 0.025 molar or 1,500 mg/l sodium chloride). If the dissolved materials are relatively innocuous, having only an osmotic effect, it is judged that the total dissolved materials in a water course may be increased to a certain extent but they should not exceed 50 milliosmoles if the fauna is to be maintained.

Many species of diatoms are very sensitive to changes in chloride and other salt concentrations. Some species, such as those in mountain streams and in black water streams of the coastal plains, can live only in waters with extremely low concentrations of salts. The addition of salts to such streams will eliminate many desirable species of diatoms and permit undesirable species to flourish. Such changes may reduce the desirable food sources and bring about nuisance problems as well. It is believed that the total dissolved material in a water course should not be increased by more than one-third of that which is characteristic of the natural conditions of such a water course.

The toxicity of substances added to natural waters often depends on the substances already present in the receiving waters. With synergism, the toxicity increases, and with antagonism it decreases. Again the reaction of the toxic substances may produce, in some cases, new products of greater toxicity, and in others, products of lesser toxicity.

In view of the many factors that become involved in the disposal of soluble materials in natural waters, it is evident that no simple answer is available. Therefore, bioassays should be used to determine the amounts of the materials that may be tolerated without reducing the productivity of the water course in question.

Recommendation: Dissolved materials are of two types: those that are toxic at very low concentrations and those, such as the salts of the earth metals, that are required in certain concentrations for a productive water and become harmful only at high concentrations by exerting an osmotic effect. If the dissolved materials are relatively innocuous, i.e., their harmful effect is an osmotic one at high concentrations, it is judged that the total dissolved materials of this type may be increased to a certain extent but they should not exceed 50 milliosmoles in waters where diversified animal populations are to be protected. Further, to maintain local conditions, total dissolved materials should not be increased by more than one-third of the concentration that is characteristic of the natural condition of the water. When dissolved materials are being increased, bioassays and field studies should be used to determine how much of the materials may be tolerated without reducing the productivity of the desired organisms.

Acidity alkalinity, and pH

Acidity and alkalinity are reciprocal terms. Acidity is produced by substances that yield hydrogen ions on hydrolysis and alkalinity is produced by substances that yield hydroxyl ions. Other definitions state that a substance is acid if it will neutralize hydroxyl ions and a substance is alkaline if it will neutralize hydrogen ions. The terms "total acidity" and "total alkalinity" are often used to express the buffering capacity of a solution. Acidity in natural waters is caused by carbon dioxide, mineral acids, weakly dissociated acids, and the salts of strong acids and weak bases. Alkalinity is caused by strong bases and the salts of strong alkalies and weak acids.

An index of the hydrogen ion activity is pH. Even though pH determinations are used as an indication of acidity and/or alkalinity, pH is not a measure of either. As pointed out in the first sentence in the previous paragraph, acidity and alkalinity are reciprocal terms. Indeed, a water may have both an acidity and alkalinity at the same time. Total acidity, by definition, is the amount of standard alkali required to bring a sample to pH 8.3. Total alkalinity, similarly, is the amount of standard acid required to bring a sample to pH 4.5. Both are expressed in equivalents of $CaCO_3$. Under these circumstances, there is a relationship between pH, acidity, and alkalinity since, by definition (see Standard Methods for the Examination of Water and Wastewater, 12th edition. 1965), any water with a pH of 4.5 or lower has no measurable alkalinity and a water with a pH of 8.3 or higher has no measurable acidity.

In natural waters, where the pH is in the vicinity of 8.3, acidity is not a factor of concern. In most productive, fresh, natural waters, the pH falls in the range between 6.5 and 8.5 (except when increased by photosynthetic activity). Some aquatic organisms have been found to live at pH 2 and lower and others at pH 10 and higher; however, such organisms are relatively few. Some natural waters with a pH of 4 support fish and other organisms. In these cases the acidity is due primarily to carbon dioxide and humic acids and the water has little buffering capacity (low total alkalinity). Other natural waters with a pH of 9.5 also support fish, but in such situations the waters are not regarded as highly productive.

Acids that dissociate to a high degree do not appear to be toxic at pH values above 6.0. They are toxic if added in sufficient quantities to reduce the pH to less than 6.0 Acids that dissociate to a low degree are often toxic at pH values considerably above 6.0. In the latter condition, toxicity is due either to the anion or to the compound itself; e.g., hydrogen cyanide (HCN), hydrogen sulfide (H_2S), and hypochlorous (HClO) and tannic acids.

Alkalies that dissociate to a high degree do not appear to be toxic at pH values below 9.0. Alkaline compounds that dissociate to a low degree are often toxic at pH values less than 9.0 and their toxicity is due either to the cation or to the undissociated molecule. Ammonium hydroxide is an example. Temporarily high pH levels often are produced in highly productive waters through photosynthetic activity of the aquatic plants by converting the carbonate to the hydroxide, which results in an increased pH. Because these high pH levels prevail for only a few hours, they do not produce the harmful effects of continuous high levels due to the presence of strong alkalies.

Addition of either acids or alkalies to waters may be harmful not only in producing adverse acid or alkaline conditions, but also by increasing the toxicity of various components in the waters. The addition of strong acids may cause the formation of carbonic acid (free CO_2) in quantities that are adverse to the well-being of the organisms present. A reduction of about 1.5 pH units can cause a thousand-fold increase in the acute toxicity of a metallo-cyanide complex. The addition of strong alkalies may cause the formation of undissociated NH_4OH or un-ionized NH_3 in quantities that may be toxic. The availability of many nutrient substances varies with the acidity and alkalinity. At higher pH values, iron tends to become unavailable to some plants.

The nonlethal limits of pH are narrower for some fish food organisms than they are for fish. For example, *Daphnia magna* does not survive experimentally in water having a pH below 6.0.

The major buffering system in natural waters is the carbonate system. This system not only neutralizes acids and bases so as to reduce the fluctuations in pH, but also forms an indispensable reservoir of carbon for photosynthesis, because there is a decided limit on the rate at which carbon dioxide can be obtained from the atmosphere to replace that in the water which becomes fixed by the plants. Thus the productivities of waters are closely correlated with the carbonate buffering systems. The addition of mineral acids preempts the carbonate buffering capacity and the original biological productivity is reduced in proportion to the degree that such capacity is exhausted. It is as necessary, therefore, to maintain the minimum essential buffering capacity as it is to confine the pH of the water within tolerable limits.

Recommendation: (1) In view of the above considerations and their importance for the production and well-being of aquatic organisms, no highly dissociated materials should be added in quantities sufficient to lower the pH below 6.0 or to raise the pH above 9.0.

(2) To protect the carbonate system and thus the productivity of the water, acid should not be added sufficient to lower the total alkalinity below 20 mg/l expressed as $CaCO_3$.

(3) The addition of weakly dissociated acids and alkalies should be regulated in terms of their own toxicities as established by bioassay procedures.

Hardness

Hardness was originally considered as the capacity of water to precipitate or neutralize soap. In natural waters, hardness is chiefly attributable to calcium and magnesium ions. Other ions, such as strontium, barium, aluminum, manganese, iron, copper, zinc, and lead also are responsible for hardness, but since they are present in relatively minor concentrations, their role usually can be ignored. Hardness, like acidity and alkalinity, is expressed in terms of $CaCO_3$ but the hardness of a water is not necessarily equal to either the acidity or alkalinity. Hardness in natural waters is generally correlated with dissolved solids but there are exceptions.

Generally, the biological productivity of a water is directly correlated with its hardness, but hardness *per se* has no biological significance because productivity depends on the specific combination of elements present. Calcium and magnesium contribute to hardness and to productivity. Most other elements that contribute to hardness reduce biological productivity and are toxic when they produce a substantial measure of hardness. Because hardness of itself has no biological significance, and because some elements which contribute to hardness may enhance biological productivity (while other contributing elements are toxic), it is recommended that the term hardness be avoided in dealing with water quality requirements for aquatic life.

Temperature

The relationships of temperature and aquatic life have been well studied. Extensive bibliographies and detailed surveys of the subject have been published by the American Society of Civil Engineers (1967), Brett (1960), Mihursky and Kennedy (1967), Raney (1966), U.S. Department of Interior, Federal Water Pollution Control Administration (1967), and Wurtz and Renn (1965).

The temperatures of the surface waters of the United States vary from 32 to over 100 F as a function of latitude, altitude, season, time of day, duration of flow, depth, and many other variables. The agents that may affect the natural temperature are so numerous that it seems unlikely that two bodies of water, even in the same latitude, would have exactly the same thermal characteristics. The fish and other aquatic life occurring naturally in each body of water are species or varieties that are competing there with various degrees of success depending on the temperature and various other conditions existing in that habitat. This adaptation extends not only to temperature and the range over which it can vary, but also to such factors as day length and the other species of animals and plants in the same habitat. The interrelationships of species, day length, and water temperature are so intimate that even a small change in temperature may have far-reaching effects. An insect nymph in an artificially warmed stream, for example, might emerge for its mating flight too early in the spring and be immobilized by the air temperature. Similarly, a fish might hatch too early in the spring to find an adequate amount of its natural food organisms because the food chain depends ultimately on plants whose abundance in turn, is a function of day length and temperature. The inhabitants of a water body that seldom becomes warmer than 70 F are placed under stress, if not killed outright, by 90 F water. Even at 75 to 80 F, they may be unable to compete successfully with organisms for which 75 to 80 F is a favorable temperature. Similarly, the inhabitants of warmer waters are at a competitive disadvantage in cool water.

Although in a rigorous climate, an animal can endure the extremes of temperature at appropriate seasons; it must be cooled gradually in the fall if it is to become acclimatized to the cold water of winter and warmed gradually in the spring if it is to withstand summer heat. Further, an organism might be able to endure a high temperature of 92 or 95 F for a few hours, but it could not do so for a period of days. Having the water change gradually with the season is important for other reasons: an increasing or decreasing temperature often serves as the trigger for spawning activities, metamorphosis, and migration. Some fresh water organisms require that their eggs be chilled before they will hatch properly.

In arriving at suitable temperature criteria, the problem is to estimate how far the natural temperature may be exceeded without adverse effects. Whatever requirements are suggested, a seasonal cycle must be retained, the changes in temperature must be gradual and the temperature reached must not be so high or so low as to damage or alter the composition of the desired population. In view of the many variables, it seems obvious that no single temperature requirement can be applied to the United States as a whole, or even to one State; the requirements must be closely related to each body of water and its population. To do this a temperature increment based on the natural water temperature is more appropriate than an unvarying number. Using an increment requires, however, that we have information on the natural temperature conditions of the water in question, and the size of the increment that can be tolerated by the desired species.

If any appreciable heat load is introduced into a stream, it must be recognized that the species' equilibrium will likely be shifted towards that characteristic of a more southerly water.

The seasonal temperature fluctuation normal to the desired biota of a particular water must be maintained. Further, the sum of any increase in temperature plus the natural peak temperature should be of short duration and below the maximum temperature that is detrimental for such periods.

Recommendation for Warm Waters: To maintain a well-rounded population of warm-water fishes, the following restrictions on temperature extremes and temperature increases are recommended:

(1) During any month of the year, heat should not be added to a stream in excess of the amount that will raise the temperature of the water (at the expected minimum daily flow for that month) more than 5 F. In lakes and reservoirs, the temperatures of the epilimnion, in those areas where important organisms are most likely to be adversely affected, should not be raised more than 3 F above that which existed before the addition of heat of artificial origin. The increase should be based on the monthly average of the maximum daily temperature. Unless a special study shows that a discharge of a heated effluent into the hypolimnion or pumping water from the hypolimnion (for discharging back into the same water body) will be desirable, such practice is not recommended.

(2) The normal daily and seasonal temperature variations that were present before the addition of heat, due to other than natural causes, should be maintained.

(3) The recommended maximum temperatures that are not to be exceeded for various species of warm-water fish are given in table III–1.

Recommendation for Cold Waters: Because of the large number of trout and salmon waters which have been destroyed, or made marginal or nonproductive, the remaining trout and salmon waters must be protected if this resource is to be preserved:

(1) Inland trout streams, headwaters of salmon streams, trout and salmon lakes and reservoirs, and the hypolimnion of lakes and reservoirs containing salmonids should not be warmed. No heated effluents should be discharged in the vicinity of spawning areas.

For other types and reaches of cold-water streams, reservoirs, and lakes, the following restrictions are recommended.

(2) During any month of the year, heat should not be added to a stream in excess of the amount that will raise the temperature of the water more than 5 F (based on the minimum expected flow for that month). In lakes and reservoirs, the temperature of the epilimnion should not be raised more than 3 F by the addition of heat of artificial origin.

(3) The normal daily and seasonal temperature fluctuations that existed before the addition of heat due to other than natural causes should be maintained.

(4) The recommended maximum temperatures that are not to be exceeded for various species of cold water fish are given in table III–1.

NOTE.—For streams, total added heat (in BTU's) might be specified as an allowable increase in temperature of the minimum daily flow expected for the month or period in question. This would allow addition of a constant amount of heat throughout the period. Approached in this way for all periods of the year, seasonal variation would be maintained. For lakes the situation is more complex and cannot be specified in simple terms.

TABLE III–1

[Provisional maximum temperatures recommended as compatible with the well-being of various species of fish and their associated biota]

93 F: Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, and gizzard shad.
90 F: Growth of largemouth bass, drum, bluegill, and crappie.
84 F: Growth of pike, perch, walleye, smallmouth bass, and sauger.
80 F: Spawning and egg development of catfish, buffalo, threadfin shad, and gizzard shad.
75 F: Spawning and egg development of largemouth bass, white, yellow, and spotted bass.
68 F: Growth or migration routes of salmonids and for egg development of perch and smallmouth bass.
55 F: Spawning and egg development of salmon and trout (other than lake trout).
48 F: Spawning and egg development of lake trout, walleye, northern pike, sauger, and Atlantic salmon.

Note.—Recommended temperatures for other species, not listed above, may be established if and when necessary information becomes available.

Dissolved oxygen

Oxygen requirements of aquatic life have been extensively studied. Excellent survey papers are presented by Doudoroff (1957), Doudoroff and Shumway (1967), Doudoroff and Warren (1962), Ellis (1937), and Fry (1960). Much of the work on temperature requirements also considers oxygen and those bibliographies are equally valuable.

Most of the research concerning oxygen requirements for freshwater organisms deals with fish, but since fish depend upon other aquatic species for food and would not remain in an area with an inadequate food supply, it seems reasonable to assume that a requirement for fish would serve also for the rest of the community. The fish themselves can be grouped into three categories according to their temperature and oxygen requirements: (1) the cold-water fish (e.g., salmon and trout), (2) the warm-water game and pan fish (e.g., bass and sunfish), and (3) the warm-water "coarse" fish (e.g., carp and buffalo). The cold-water fish seem to require higher oxygen concentrations than the warm-water varieties. The reason is not known, but it may be related to the fact that, for half saturation, trout hemoglobin requires an oxygen partial pressure three or four times that required by carp hemoglobin under similar circumstances. Warm-water game and pan fish seem to require a higher concentration than the "coarse" fish, probably because the former are more active and predatory.

Relatively little of the research on the oxygen requirements of fish in any of these three categories is applicable to the problem of establishing oxygen criteria because the endpoints have usually been too crude. It is useless in the present context to know how long an animal can resist death by asphyxiation at low dissolved oxygen concentrations; we must know instead the oxygen concentration that will permit an aquatic population to thrive. We need data on the oxygen requirements for egg development, for newly hatched larvae, for normal growth and activity, and for completing all stages of the reproductive cycle. It is only recently that experimental work has been undertaken on the effects of oxygen concentration on these more subtle endpoints. As yet, only a few species have been studied.

One of the first signs that a fish is being affected by a reduction of dissolved oxygen (DO) concentration is an increase in the rate at which it ventilates its gills, a process accomplished in part by an increase in the frequency of the opercular movements. The half dozen or so species (chiefly warm-water game and pan fish) that have been reported so far show a significant increase in frequency as the DO concentration is reduced from 6 to 5 mg/l (at about 72 F) and a greater increase from 5 to 4 mg/l. If the opercular rate is taken as the criterion by which the adequacy of an oxygen concentration is to be judged, then such evidence as we have indicates 6 mg/l as the required dissolved oxygen concentration. Several field studies have shown, however, that good and diversified fish populations can occur in waters in which the dissolved oxygen concentration is between 6 and 5 mg/l in the summer, suggesting that a minimum of 6 mg/l is probably more stringent than necessary for warm-water fishes. Because the oxygen content of a body of water does not remain constant, it follows that if the dissolved oxygen is never less than 5 mg/l it must be higher part of the time. In some cases, good populations of warm-water fish, including game and pan fishes, occur in waters in which the dissolved oxygen may be as low as 4 mg/l for short periods. Three mg/l is much too low, however, if normal growth and activity are to be maintained. It has been reported that the growth of young fish is slowed markedly if the oxygen concentration falls to 3 mg/l for part of the day, even if it rises as high as 18 mg/l at other times. It is for such reasons as this that oxygen criteria cannot be based on averages. Five and 4 mg/l are close to the borderline of oxygen concentrations that are tolerable for extended periods. For a good population of game and pan fishes, the concentration should be considerably more than this.

The requirements of the different stages in the life cycles of aquatic organisms must be taken into account. An oxygen concentration that can be tolerated by an adult animal, with fully developed respiratory apparatus, less intense metabolic requirements, and the ability to move away from adverse conditions, could easily be too low for eggs and larval stages. The eggs are especially vulnerable to oxygen lack because they have to depend upon oxygen diffusing into them at a rate sufficient to maintain the developing embryos. Hatching, too, is a critical time; recently hatched young need relatively more oxygen than adults, but until they become able to swim for themselves (unless they are in flowing water) they must depend upon the oxygen supply in the limited zone around them. These problems are not as great among species that tend their eggs and young, suspend their eggs from plants, or have pelagic eggs, as they are for salmonids. Salmonids bury their eggs in the gravel of the stream away from the main flow of the water thereby requiring a relatively high oxygen concentration in the water that does reach them.

Recommendation: In view of the above considerations and with the proviso that future research may make revision necessary, the following environmental conditions are considered essential for maintaining native populations of fish and other aquatic life:

(1) For a diversified warm-water biota, including game fish, daily DO concentration should be above 5 mg/l, assuming that there are normal seasonal and daily variations above this concentration. Under extreme conditions, however, and with the same stipulation for seasonal and daily fluctuations, the DO may range between 5 mg/l and 4 mg/l for short periods of time, provided that the water quality is favorable in all other respects. In stratified eutrophic and dystrophic lakes, the DO requirements may not apply to the hypolimnion. In shallow unstratified lakes, they should apply to the entire circulating water mass.

These requirements should apply to all waters except administratively established mixing zones. In lakes, such mixing zones must be restricted so as to limit the effect on the biota. In streams, there must be no blocks to migration and there must be adequate and safe passageways for migrating forms. These zones of passage must be extensive enough so that the majority of plankton and other drifting organisms are protected (see section on zones of passage).

(2) For the cold water biota, it is desirable that DO concentrations be at or near saturation. This is especially important in spawning areas where DO levels must not be below 7 mg/l at any time. For good growth and the general well-being of trout, salmon, and other species of the biota, DO concentrations should not be below 6 mg/l. Under extreme conditions they may range between 6 and 5 mg/l for short periods provided that the water quality is favorable and normal daily and seasonal fluctuations occur. In large streams that have some stratification or that serve principally as migratory routes, DO levels may be as low as 5 mg/l for periods up to 6 hours, but should never be below 4 mg/l at any time or place.

(3) DO levels in the hypolimnion of oligotrophic small inland lakes and in large lakes should not be lowered below 6 mg/l at any time due to the addition of oxygen-demanding wastes or other materials.

Carbon dioxide

An excess of "free" carbon dioxide (as distinguished from that present as carbonate and bicarbonate) may have adverse effects on aquatic animals. These effects range from avoidance reactions and changes in respiratory movements at low concentrations, through interference with gas exchange at higher concentrations, to narcosis and death if the concentration is increased further. The respiratory effects seem the most likely to be of concern in the present connection.

Since the carbon dioxide resulting from metabolic processes leaves the organisms by diffusion, an increase in external CO_2 concentration will make it more difficult for it to diffuse out of the organism. Thus, it begins to accumulate internally. The consequences of this internal accumulation are best known for fish, but presumably the principles are the same for other organisms. As the CO_2 accumulates, it depresses the blood pH, and this may have detrimental effects. Probably more important, however, is the fact that the greater the blood CO_2 concentration, the less readily will the animal's hemoglobin combine with dissolved oxygen. Thus the presence of much CO_2 raises the minimum oxygen concentration which is tolerable. Since the combination of oxygen with hemoglobin is inversely related to temperature, it is obvious that CO_2, temperature, and oxygen are closely related. Insufficient data are available at present to permit us to state the greatest amount of dissolved carbon dioxide that all types of aquatic organisms can tolerate and how these tolerable concentrations vary with temperature and dissolved oxygen. Studies of the effect of CO_2 on the oxygen requirements of several species of fish indicate that CO_2 concentrations of the order of 25 mg/l should not be detrimental, provided the oxygen concentration and temperature are within the recommended limits.

Recommendation: According to our rather meagre knowledge of the subject, it is recommended that the free CO_2 concentration should not exceed 25 mg/l.

Oil

Oil slicks are barely visible at a concentration of about 25 gal/sq mi (Amer. Petroleum Inst. 1949). At 50 gal/sq mi, an oil film is 3.0×10^{-6} inches thick and is visible as a silvery sheen on the surface. Sources of oil pollution are bilge and ballast waters from ships, oil refinery wastes, industrial plant wastes such as oil, grease, and fats from the lubrication of machinery, reduction works, plants manufacturing hydrogenated glycerides, free fatty acids, and glycerine, rolling mills, county drains, storm-water overflows, gasoline filling stations, and bulk stations.

Wiebe (1935) showed that direct contact by fish (bass and bream) with crude oil resulted in death caused by a film over the gill filaments. He also demonstrated that crude oil contains a water-soluble fraction that is very toxic to fish. Galtsoff, et al. (1935) showed that crude oil contains substances soluble in sea water that produce an anaesthetic effect on the ciliated epithelium of the gills of oysters. Free oil and emulsions may act on the epithelial surfaces of fish gills and interfere with respiration. They may coat and destroy algae and other plankton, thereby removing a source of fish food, and when ingested by fish they may taint their flesh.

Setteable oily substances may coat the bottom, destroy benthic organisms, and interfere with spawning areas. Oil may be absorbed quickly by suspended matter, such as clay, and then due to wind action or strong currents may be transported over wide areas and deposited on the bottom far from the source. Even when deposited on the bottom, oil continuously yields water-soluble substances that are toxic to aquatic life.

Films of oil on the surface may interfere with reaeration and photosynthesis and prevent the respiration of aquatic insects such as water boatmen, backswimmers, the larvae and adults of many species of aquatic beetles, and some species of aquatic Diptera (flies). These insects surface and carry oxygen bubbles beneath the surface by means of special setae which can be adversely affected by oil. Berry (1951) reported that oil films on the lower Detroit River are a constant threat to waterfowl. Oil is detrimental to waterfowl by destroying the natural buoyancy and insulation of their feathers.

A number of observations made by various authors in this country and abroad record the concentrations of oil in fresh water which are deleterious to different species. For instance, penetration of motor oil into a fresh water reservoir used for holding crayfish in Germany caused the death of about 20,000 animals (Seydell, 1913). It was established experimentally that crayfish weighing from 35 to 38 g die in concentrations of 5 to 50 mg/l within 18 to 60 hours. Tests with two species of fresh water fish, ruff (small European perch), and whitefish (fam. Coregonidae) showed that concentrations of 4 to 16 mg/l are lethal to these species in 18 to 60 hours.

The toxicity of crude oil from various oil fields in Russia varies depending on its chemical composition. The oil used by Veselov (1948) in the studies of the pollution of Belaya River (a tributary in the Kama in European Russia) belongs to a group of methano-aromatic oils with a high content of asphalt, tar compounds, and sulfur. It contains little paraffin and considerable amounts of benzene-ligroin. Small crucian carp (*Carassius carassius*) 7–9 cm long were used as the bioassay test animal. This is considered to be a hardy fish that easily withstands adverse conditions. The water soluble fraction of oil was extracted by shaking 15 ml of oil in 1 liter of water for 15 minutes. The oil film was removed by filtration. Dissolved oxygen was controlled. A total of 154 tests were performed using 242 fishes. The average survival time was 17 days at the concentration of 0.4 ml/l of oil but only 3 days at the concentration of 4 ml/l. Further increase in concentration had no appreciable effect on fish mortality.

Seydell (1913) stated that the toxicity of Russian oil is due to naphthenic acids, small quantities of phenol, and volatile acids (Veselov, 1948).

Cairns (1957) reports the following 96-hour TL_m values of naphthenic acid for bluegill sunfish (*Lepomis macrochirus*)—5.6 mg/l; pulmonate snail (*Physa heterostropha*)—6.1 to 7.5 mg/l (in soft water), and diatom (species not identified)—41.8 to 43.4 mg/l in soft water and 28.2 to 79.8 mg/l in hard water. Naphthenic acid (cyclohexane carboxylic acid) is extracted from petroleum and is used in the manufacture of insecticides, paper, and rubber.

Chipman and Galtsoff (1949) report that crude oil in concentrations as low as 0.3 mg/l is extremely toxic to fresh water fish. Dorris, Gould, and Jenkins (1960) made an intensive study of the toxicity of oil refinery effluents to fathead minnows in Oklahoma. By standard bioassay procedures, they found that mortality varied between 3.1 percent to 21.5 percent after 48 hours of exposure to untreated effluents. They concluded that toxicity rather than oxygen demand is the most important effect of oil refinery effluents on receiving streams.

Pickering and Henderson (1966b) reported the results of acute toxicity studies of several important petrochemicals to fathead minnows, bluegills, goldfish, and guppies in both soft water and hard water. Standard bioassay methods were used. Because several of the compounds tested have low solubility in water, stock solutions were prepared by blending the calculated concentrations into 500 ml of water before addition to the test container. Where necessary, pure oxygen was supplied by bubbling at a slow rate. The petrochemicals tested were benzene, chlorobenzene, 0-chlorophenol, 3-chloropropene, 0-cresol, cyclohexane, ethyl benzene, isoprene, methyl methacrylate, phenol, 0-phthalic anhydride, styrene, toluene, vinyl acetate, and xylene. These petrochemicals are similar in their toxicities to fish, with 96-hour TL_m values ranging from 12 to 368 mg/l. Except for isoprene and methyl methacrylate, which are less toxic, values for all four species of fish for the other petrochemicals ranged from 12 to 97 mg/l, a relatively small variation. In general, 0-chlorophenol and 0-cresol are the most toxic and methyl methacrylate and isoprene are the least toxic.

Recommendation: In view of available data, it is concluded that to provide suitable conditions for aquatic life, oil and petrochemicals should not be added in such quantities to the receiving waters that they will: (1) produce a visible color film on the surface, (2) impart an oily odor to water or an oily taste to fish and edible invertebrates, (3) coat the banks and bottom of the water course or taint any of the associated biota, or (4) become effective toxicants according to the criteria recommended in the "Toxicity" section.

Turbidity

Turbidity is caused by the presence of suspended matter such as clay, silt, finely divided organic matter, bacteria, plankton, and other microscopic oragnisms. Turbidity is an expression of the optical property of a sample of water which causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. Excessive turbidity reduces light penetration into the water and, therefore, reduces photosynthesis by phytoplankton organisms, attached algae, and submersed vegetation.

The Jackson candle turbidimeter (Standard Methods for the Examination of Water and Wastewater, 12th edition, 1965) is the standard instrument for making measurements of turbidity. Field determinations, however, are made with direct-reading colorimeters calibrated for this test and the results are expressed as Jackson turbidity units (JTU).

Silt and sediment are particularly damaging to gravel and rubble-type bottoms. The sediment fills the interstices between gravel and stones, thereby eliminating the spawning grounds of fish and the habitat of many aquatic insects and other invertebrate animals such as mollusks, crayfish, fresh water shrimp, etc. Tarzwell (1957) observed that bottom organisms from a silted area averaged only 36 organisms/sq ft compared to 249/sq ft in a non-silted area. Smith (1940) reported that silting reduced the bottom fauna of the Rogue River by 25 to 50 percent. Observations in Oregon by Wagner (1959) and Ziebell (1960) showed an 85-percent decline in productivity of aquatic insect populations below a gravel dragline operation. Turbidities in the affected area were increased from zero to 91 mg/l and suspended solids from 2 mg/l upstream to 103 mg/l downstream.

Buck (1956) investigated several farm ponds, hatchery ponds, and reservoirs over a 2-year period. He observed that the maximum production of 161.5 lb/acre occurred in farm ponds where the average turbidity was less than 25 JTU. Between 25 and 100 JTU, fish yield dropped 41.7 percent to 94 lb/acre, and in muddy ponds, where turbidity exceeded 100 JTU, the yield was only 29.3 lb/acre or 18.2 percent of clear ponds.

Herbert and Merkens (1961), using a mixture of kaolin and diatomaceous earth, demonstrated that long-term exposure of rainbow trout to 100–200 mg/l could be harmful. At 270 and 810 mg/l, a high percentage of the fish died. Wallen (1951) studied the effects of montmorillonite clay on 16 species of warm-water fish. Results are shown in table III–2. It is shown that fish can tolerate high turbidities for short periods, a fortunate adaptation for river species. Fish productivity is ultimately dependent upon plant life and a good bottom fauna. There can be little of either above 200 JTU if that turbidity is maintained continuously. The Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Commission (ORSANCO) Second Progress Report (1956) points out that fish withstand turbidities of 5,000 mg/l or more with no direct harmful results, but the productivity of the bottom areas is very low and the fish populations are small.

TABLE III–2. Average Turbidities Found To Be Fatal to Fish

Species	Length of exposure (days)	Turbidity (mg/l)
Large mouth bass	7.6	101,000
Pumpkin seed sunfish	13	69,000
Channel catfish	9.3	85,000
Black bullhead	17	222,000
Golden shiner	7.1	166,000

Ellis (1937) summarized the results of 2,344 light penetration determinations made at 585 stations on streams throughout the United States. The determinations were made of the millionth intensity depth (m.i.d.), which is the depth in millimeters of water of the given turbidity required to screen out 99.9999 percent of the light entering at the surface. A photoelectric apparatus described by Ellis (1934b) was used and determinations were made after filtering the water through bolting silk.

The turbidity of rivers varies widely in different parts of the country. Ellis (1937) defined clear streams as those with a m.i.d. of 5.00 to infinity; cloudy streams, 4.90–1.00 meters; turbid, 0.99–0.50; very turbid, 0.49–0.30; muddy, 0.29–0.15; very muddy, 0.14–0.00 meters.

In Mississippi River side channels and flowing stream tributaries with good fish fauna, 4 percent were clear, 11 percent cloudy, 3 percent were very muddy. In these waters, with medium, poor, or no fish fauna 1 percent were clear, 18 percent cloudy, 11 percent turbid, 14 percent very turbid, 38 percent muddy, and 18 percent very muddy.

Based on 6,000 light penetration determinations on inland streams, he concluded that, for good production of fish and aquatic life, the silt load of these streams should be reduced so that the millionth intensity depth would be greater than 5 meters.

Good farming practices can do a great deal to prevent silt from reaching streams and lakes. Road building and housing development projects, placer mining, strip mining, coal and gravel washing, and unprotected road cuts are important sources of turbidity that can be reduced with planning, good housekeeping, and regulation.

Natural turbidities within watersheds should be determined. For example, in some Western States many streams have a turbidity below 25 JTU for most of the year. In those states, the water pollution control agency might specify that no wastes should be discharged which would raise the turbidity of the receiving water above 25 JTU.

From the above discussion it can be seen that natural turbidity varies greatly in different parts of the country.

Recommendation: Turbidity in the receiving water due to a discharge should not exceed 50 JTU in warm-water streams or 10 JTU in cold-water streams.

There should be no discharge to warm-water lakes which will cause turbidities exceeding 25 Jackson Units. The turbidity of cold-water or oligotrophic lakes should not exceed 10 units.

Settleable solids

Settleable solids include both inorganic and organic materials. The inorganic components include sand, silt, and clay originating from such sources as erosion, placer mining, mine tailing wastes, strip mining, gravel washing, dusts from coal washeries, loose soils from freshly plowed farm lands, highway, and building projects. The organic fraction includes such settleable materials as greases, oils, tars, animal and vegetable fats, paper mill fibers, synthetic plastic fibers, sawdust, hair, greases from tanneries, and various settleable materials from city sewers. These solids may settle out rapidly and bottom deposits are often a mixture of both inorganic and organic solids. They may adversely affect fisheries by covering the bottom of the stream or lake with a blanket of material that destroys the bottom fauna or the spawning grounds of fish. Deposits containing organic materials may deplete bottom oxygen supplies and produce hydrogen sulfide, carbon dioxide, methane, or other noxious gases.

Some settleable solids may cause damage by mechanical action.

Water Quality Criteria for European Freshwater Fish (European Inland Fisheries Advisory Commission, 1964) discusses chemically inert solids in waters that are otherwise satisfactory for the maintenance of freshwater fisheries. It is indicated that good or moderate fisheries can be maintained in waters that normally contain 25 to 80 mg/l suspended solids, but that the yield of fish might be lower than in waters containing 25 mg/l or less. Waters normally containing 80 to 400 mg/l suspended solids are unlikely to support good freshwater fisheries.

Recommendation: Since it is known that even minor deposits of settleable materials inhibit the growth of normal stream or lake flora and fauna, it is recommended that no settleable materials be added to these waters in quantities that adversely affect the natural biota.

Color

The color of water is attributed to substances in solution after the suspensoids have been removed. It may be of organic or mineral origin. Organic sources are humic materials, peat, plankton, rooted and floating aquatic plants, tannins, etc. Inorganic sources are metallic substances such as iron and manganese compounds and chemicals, dyes, etc. Many industries discharge materials that contribute to the color of water. Among them are pulp and paper mills, textile mills, refineries, manufacturers of chemicals and dyes, explosives, nailworks, tanneries, etc.

Standard Methods for the Examination of Water and Wastewater, 12th edition (1965), describes the standard platinum-cobalt method of determining color after centrifugation. The unit of color considered as standard is the color produced by one mg/l of platinum in water. Results are expressed as units of color. Color in excess of 50 units may limit photosynthesis and have a deleterious effect upon aquatic life, particularly phytoplankton, and the benthos.

Water absorbs light differentially. A layer of distilled water 1 meter in thickness absorbs 53 percent of the solar radiation. It absorbs 30 percent of the red-orange band (6,500 angstrom units) but less than 5 percent of the blue (4,500 angstrom units). These are the portions of the spectrum that are absorbed and utilized to the greatest extent by chlorophyll. The band at 7,500 angstrom units is over 90 percent absorbed.

Natural waters absorb far more light. The light intensity at which the amount of oxygen produced photosynthetically is balanced by the amount of oxygen used for respiration in some submerged vascular plants is 5% of full sunlight on clear summer days. It is estimated that 25 to 50 percent of full sunlight is necessary for many green aquatic plants to reach maximum photosynthesis. The ORSANCO committee observed that the 25-percent level of solar radiation is not reached in many of the larger streams and they considered it desirable to restrict the addition of any substances that reduce light penetration and hence limit the primary productivity of aquatic vegetation.

Recommendation: For effective photosynthetic production of oxygen, it has been found that at least 10 percent of incident light is required. Therefore, 10 percent of the incident light should reach the bottom of any desired photosynthetic zone in which adequate dissolved oxygen levels are to be maintained.

Floating materials

Floating materials include sawdust, peelings and other cannery wastes, hair and fatty materials from tanneries, wood fibers, containers, scums, oil, garbage, floating materials from untreated municipal and industrial wastes, tars and greases, and precipitated chemicals.

Wastes from paper mills, vinegar plants, cane mills, and other industries may contribute nutrients or produce conditions in streams that foster the growth of *Sphaerotilus* (Chlamydobacteriales) or similar iron or sulfur bacteria. These floating growths not only clog fishermen's nets, but also smother out the spawning grounds and habitat of all forms of aquatic life.

Recommendation: All such floating and settleable substances should be excluded from streams and lakes.

Tainting substances

Among the materials that are responsible for objectionable tastes in fish are hydrocarbons, phenolic compounds, sodium pentachlorophenate (used for slime control in cooling towers), coal tar wastes, gas wastes, sewage containing phenols, coal-coking wastes, outboard motor exhaust wastes, and petroleum refinery wastes. Kraft paper mill wastes, sulfides, mercaptans, turpentine, wastes from synthetic rubber and explosives factories, algae, resins and resin acids also contribute to objectional tastes in fish. Twenty gallons per acre of kerosene or diesel fuel will produce an off-flavor in bass and bluegills which persists for 4 to 6 weeks. The Aquatic Life Advisory Committee of ORSANCO in its Third Progress Report (1960), lists the concentrations (table III–3) of phenolic substances that cause taste and odor. Albersmeyer and Erichsen (1959) found that carbolated oil and light oil, both dephenolated, impart a taste to fish flesh more pronounced than that caused by naphthalene and methyl naphthalene. They concluded that the hydrocarbons are more responsible for tastes in fish flesh than the phenolic compounds. Boetius (1954) found that chlorophenol could produce unpleasant flavor in fish at a concentration of only 0.0001 mg/l.

TABLE III–3. Concentration of Phenolic Compounds That Cause Tainting of Fish Flesh

After Bandt (1955) page 77 (except for phenol).

Compound or waste	Concentration affecting taste and odor (mg/l)	Fish tested
Pure compounds:		
Phenol	15 to 25	Trout, carp, tench, chub, eel, minnow, perch, bluegill, pike, goldfish.
Cresols	10	Tench, carp, eel, trout, minnow.
Xylenols	1 to 5	Roach, perch, carp.
Pyrocatechol	2 to 5	Perch, carp, roach.
Pyrogallol	20 to 30	Roach, carp.
P-Quinone	0.5	Carp, tench, roach.
Pyridine	5	Roach, carp.
Naphthalene	1	Roach.
Alpha Naphthol	0.5	Roach, carp.
Quinoline	0.5 to 1.0	do.
Chlorophenol	0.1	
Mixed phenolic wastes:		
Coal-coking wastes	0.02 to 0.1	Freshwater fish.
Coal-tar wastes	0.1	do.
Phenols in polluted river	0.02 to 0.15	Minnows.
Sewage containing phenols	0.1	Freshwater fish.

A preliminary laboratory study (English, McDermott, and Henderson, 1963) shows that outboard motor exhaust damages the quality of water in several ways, the most noticeable of which is causing unpleasant taste and odor in the water and off-flavoring of fish flesh. A later field study, English et al. (1963a, b) and Surber et al. (1965) determined the threshold level of tainting of fish in pond and lake waters to be about 2.6 gal/acre-foot of fuel, accumulating over a 2-month period. The gasoline used was regular grade and the lubricating oil (½ pint/gal) was a popular brand of packaged outboard motor oil.

Recommendation: Materials that impart odor or taste to fish flesh or other freshwater edible products such as crayfish, clams, prawns, etc., should not be allowed to enter receiving waters at levels that produce tainting. Where it seems probable that a discharge may result in tainting of edible aquatic products, bioassays and taste panels are suggested for determining whether tainting is likely.

Radioactive materials in fresh and marine waters

Ionizing radiation, when absorbed in living tissue in quantities substantially above that of natural background, is recognized as injurious. It is necessary, therefore, to prevent excessive levels of radiation from reaching any organism we wish to preserve, be it human, fish, or invertebrate. Beyond the obvious fact that they emit ionizing radiation, radioactive wastes are similar in many respects to other chemical wastes. Man's senses cannot detect radiation unless it is present in massive amounts. Radiation can be detected, however, by means of electronic instruments and quantities present at very low levels in the environment can be measured with remarkable accuracy. Because of the potential danger, the disposal of radioactive materials has been well planned and controlled. Injuries and loss of life from disposal of radioactive materials or from accidents involving these materials have been minimal. Four factors have contributed to this safety record: (1) scientists and legislators were aware of the dangers associated with the release of radioactive materials into the environment prior to the need for disposal; (2) research has progressed to protect man against radiation effects and levels of radiation that could be released; (3) as knowledge of nuclear energy increased, standards were developed for handling, shipping, and disposing of radioactive substances; and (4) an extensive monitoring program was inaugurated and has been functioning for years.

Upon introduction into an aquatic environment, radioactive wastes can: (1) remain in solution or in suspension, (2) precipitate and settle to the bottom, or (3) be taken up by plants and animals. Immediately upon introduction of radioactive materials into the water, certain factors interact to dilute and disperse these materials, while simultaneously other factors tend to concentrate the radioactivity. Among those factors that dilute and disperse radioactivity are currents, turbulent diffusion, isotopic dilution, and biological transport. Radioactivity is concentrated biologically by uptake directly from the water and passage through food webs, chemically and physically by adsorption, ion exchange, coprecipitation, flocculation, and sedimentation.

Radioactive wastes in the aquatic environment may be cycled through water, sediment, and the biota. Each radionuclide tends to take a characteristic route and has its own rate of movement from component to component prior to coming to rest in a temporary reservoir, one of the three components of the ecosystem. Isotopes can move from the water to the sediments or to the biota. In effect, the sediments and biota compete for the isotopes in the water. Even though in some instances sediments are initially successful in removing large quantities of radionuclides from the water, and thus preventing their immediate uptake by the biota, this sediment-associated radioactivity may later affect many benthic species by exposing them to radiation. Also, any radioactivity leached from the sediments back to the water again becomes available for uptake by the biota. Even before the radioactivity is leached from the sediment, it may become available to the biota due to a variation in the strength of the bonds between the different radionuclides and the sediment particles. Loosely bound radionuclides can be "stripped" from particles of sediment and utilized by bottom-feeding organisms.

Plants and animals, to be of any significance in the cycling of radionuclides in the aquatic environment, must accumulate the radionuclide, retain it, be eaten by another organism, and be digestible. However, even if an organism accumulates and retains a radionuclide and is not eaten before it dies, the radionuclide will enter the "biological cycle" through organisms that decompose the dead organic material into its elemental components. Plants and animals that become radioactive in this biological cycle can pose a health hazard when eaten by man.

Aquatic life may receive radiation from radionuclides present in the water and substrate and also from radionuclides that may accumulate within their tissues. Humans can acquire radionuclides via many pathways, but among the most important are drinking water or edible fish and shellfish that have concentrated nuclides from the water. In order to prevent unacceptable doses of radiation from reaching humans, fish, and other important organisms, the concentrations of radionuclides in water, both fresh and marine, must be restricted.

The effects of radiation on organisms have been the subject of intense investigation for many years. Careful consideration of pertinent portions of the vast amount of available information by such organizations as the International Commission on Radiological Protection (ICRP), the National Committee on Radiation Protection and Measurements (NCRP), and the Federal Radiation Council (FRC) has resulted in recommendations on the maximum doses of radiation that people may be allowed to receive under various circumstances (U.S. Department of Commerce, 1963). The recommended levels for the general public are substantially more conservative than those for persons who work with radiation sources or radionuclides, but in both cases the recommended levels assume that the exposure will be sustained essentially throughout the life or period of employment of the person.

The ICRP and NCRP have calculated the quantities of individual radionuclides that a person can ingest each day without accumulating levels in various body organs that deliver radiation doses in excess of the recommended limits. These quantities contained in the volume of water ingested daily (2.2 liters) are referred to as "maximum permissible concentrations (MPC) in water." The FRC, recognizing that people may ingest radionuclides from foods and other sources as well as from drinking water, has provided guidance on the basis of transient rates of intake from all sources, but only for a few nuclides (radium-226, iodine-131, strontium-90, and strontium-89).

The PHS Drinking Water Standards (USDHEW, 1962) are responsive to the recommendations of the FRC, ICRP, and NCRP, and provide appropriate protection against unacceptable radiation dose levels to people where drinking water is the only significant source of exposure above natural background. Where fish or other fresh or marine products that have accumulated radioactive materials are used as food by humans, the concentrations of the nuclides in the water must be further restricted to provide assurance that the total intake of radionuclides from all sources will not exceed the recommended levels.

The radiation dose received by fish and other aquatic forms will be greater than that received by people who drink the water or eat the fish. Even so, this does not place the fish in risk of suffering radiation damage. The radiation protection guides for people have been established with prudence, for continued exposure over a normal life span, and with appropriate risk (safety) factors. Virtually all of the available evidence shows that the concentrations of radionuclides in fish and shellfish that would limit their use as food are substantially below the concentrations that would injure the organisms from radiation. Therefore, at this time there appears to be no need for establishing separate criteria for radioactive materials in water beyond those needed to limit the intake to humans.

Recommendation: (1) No radioactive materials should be present in receiving waters as a consequence of the failure of an installation to exercise practical and economical controls to minimize releases. This recommendation is responsive to the recommendations of the FRC that: "There can be no single permissible or acceptable level of exposure without regard to the reason for permitting the exposure. It should be general practice to reduce exposure to radiation, and positive effort should be carried out to fulfill the sense of these recommendations. It is basic that exposure to radiation should result from a real determination of its necessity."

(2) No radionuclide or mixture of radionuclides should be present at concentrations greater than those specified in the PHS Drinking Water standards (USDHEW, 1962). This recommendation assures that people will receive no more than acceptable amounts

> of radioactive materials from aquatic sources and that fish living in the water will not receive an injurious dose of radiation.
>
> (3) The concentrations of radioactive materials present in fresh, estuarine, and marine waters should be less than those that would require restrictions on the use of organisms harvested from the area in order to meet the Radiation Protection Guides recommended by the Federal Radiation Council.

This recommendation assures that fish and other fresh water and marine organisms will not accumulate radionuclides to levels that would make them unacceptable for human food. It also limits the radiation dose that the organisms would receive from internally deposited nuclides to levels below those that may be injurious. Some workers (Carritt, 1959; Isaacs, 1962; Pritchard, 1959) have recommended "maximum permissible levels for sea water" based on various assumptions of dispersion, uptake by marine organisms, and the use of the organisms as food by people. While these recommendations are most useful as a first approximation in predicting safe rates of discharge of radioactive wastes, their applicability as water quality criteria is limited and they are not intended for use in fresh or estuarine waters where the concentrations of a great variety of chemical elements vary widely. Because it is not practical to generalize on the extent to which many of the important radionuclides will be concentrated by fresh water and marine forms, nor on the extent to which these organisms will be used for food by people, no attempt is made here to specify MPC for either sea water or fresh water in reference to uptake by the organisms. Rather, each case requires a separate evaluation that takes into account the peculiar features of the region. Such an evaluation should be approved by an agency of the State or Federal Government in each instance of radioactive contamination in the environment. In each particular instance of contamination, the organisms present, the extent to which these organisms concentrate the radionuclides, and the extent to which man uses the organisms as food must be determined, as well as the rates of release of radionuclides must be based on this information.

Plant nutrients and nuisance organisms

All terrestrial biological processes plus the majority of man's activities ultimately result in waste products in various stages of decomposition. A portion of these sooner or later enter surface freshwaters. These waste products include a rather abundant amount of plant nutrients such as nitrogen, phosphorus, carbon, and other elements. Subsequently, these plant nutrients are incorporated into organic matter by aquatic plants.

Surface water areas are like land areas in that some type of vegetation will occupy any suitable habitat. Thus, the more abundant the nutrient supply, the more dense the vegetation, provided other environmental factors are favorable. In the aquatic habitat, these growths may be bacteria, aquatic fungi, phytoplankton, filamentous algae, submersed, emersed, floating, and marginal water plants. Practically all aquatic plants may be desirable at one time or another and in one habitat or another. However, when they become too dense or interfere with other uses of the water or of the aquatic habitat, they become nuisance growths.

Some sheath-forming bacteria are the primary nuisance-type growths in rivers, lakes, and ponds. A notable problem associated with this group occurs in areas subjected to organic enrichment. The most common offenders belong to the genus *Sphaerotilus*. These bacteria are prevalent in areas receiving raw domestic sewage, improperly stabilized paper pulp effluents or effluents containing simple sugars. The growths they produce interfere with fishing by fouling lines, clogging nets, and generally creating unsightly conditions in the infested area. Their metabolic demands while they are living and their decomposition after death impose a high BOD load on the stream and can severely deplete the dissolved oxygen. It has been suggested that large populations of *Sphaerotilus* render the habitat noxious to animals and hence its presence may actively exclude desirable fish and invertebrates.

The freshwater algae are diverse in shape, color, size, and habitat. A description of all species of algae would be as comprehensive as writing about all land plants, mosses, ferns, fungi, and seed plants.

They may be free floating (planktonic) or they may grow attached to the substrate (benthic or epiphytic types). They may be macroscopic or microscopic and are single-celled, colonial, or filamentous. They are the basic link in the conversion of inorganic constituents in water into organic matter. When present in sufficient numbers, these plants impart a green, yellow, red, or black color to the water. They may also congregate at or near the water surface and form so-called "waterbloom" or "scum."

A major beneficial role of algae is the removal of carbon dioxide from the water by photosynthesis during daylight and the production of oxygen. Algae, like other organisms, continually respire and produce carbon dioxide. The amount of oxygen produced during active photosynthesis is many times the amount of carbon dioxide released during the night or on cloudy days when photosynthesis is inhibited or stopped.

Limited concentrations of algae are not troublesome in surface waters; however, overproduction of various species is considered undesirable for many water uses. A relatively abundant growth of planktonic algae in waters 3 feet or deeper will shade the bottom muds sufficiently to prevent germination of seeds and halt the growth of practically all rooted submersed and emersed aquatics, thus removing an important source of food for ducks and other water fowl.

Some blue-green algae, many green algae, and some diatoms produce odors and scums that make waters less desirable for swimming. Dense growths of such planktonic algae may limit photosynthetic activity to a layer only a few inches beneath the surface of the water. Under certain conditions, the populations of algae may die and their decomposition will deplete dissolved oxygen in the entire body of water. Certain sensitive people are allergic to many species of planktonic algae blooming in waters used for swimming.

It is claimed that some species of algae cause gastric disturbances in humans who consume such infested waters. Several species of blue-green algae produce, under certain conditions, toxic organic substances that kill fish, birds, and domestic animals. Some of the genera that contain species which may produce toxins are *Anabaena*, *Anacystis*, *Aphanizomenon*, *Coelosphaerium*, *Gloeotrichia*, *Microcystis*, *Nodularia*, and *Nostoc*. Some species of *Chlorella*, a green alga, also are toxic.

Various species of single, as well as branched filamentous forms of algae, grow in both cool and warm weather and when they become overabundant are generally considered to be a nuisance in whatever body of water they occur. Most species of these algae are generally distributed over the United States.

Many forms of plankton and filamentous algae clog sand filters in water treatment plants, produce undesirable tastes and odors in drinking water, and secrete oily substances that interfere with domestic use and manufacturing processes. Some algae cause water to foam during heating as well as metal corrosion and the clogging of screens, filters, and piping. Algae also coat cooling towers and condensers causing these units to become ineffective. In Lake Superior, complaints have been made that diatoms such as *Tabellaria*, *Synedra*, *Cymbella*, and *Fragilaria*, and the chrysophyte, *Dinobryon*, may be the cause of slimes on fishnets.

Filamentous algae may interfere with the operation of irrigation systems by clogging ditches, wires, and screens and thus seriously impede the flow of water. Filamentous algae in ponds, lakes, and reservoirs may cause depletion of naturally occurring and added nutrients that could otherwise be used to produce unicellular algae that are more commonly used as food by fish. Dense growths of filamentous algae may reduce the total fish production and seriously interfere with harvesting the fish either by hook and line fishing, seining, or draining. Such growths can also cause overpopulation, resulting in stunting and the presence of large numbers of small fish. Under certain conditions, growths of filamentous algae on pond or lake bottoms become so dense that they eliminate spawning areas of fish and possibly interfere with the production of invertebrate fish food.

Submersed plants are those which produce all or most of their vegetative growth beneath the water surface. In many instances these plants have an underwater leaf form, a totally different floating or emersed leaf form, and flowers on an aerial stalk. Abundant growth of these weeds is dependent upon depth and turbidity of water, and substratum. For most submersed plants in clear water, 8 to 10 feet is the maximum depth for growth in clear water as they must receive sufficient light for photosynthesis when they are seedlings. Most of these submersed aquatic plants appear capable of absorbing nutrients as well as herbicides through either their roots or vegetative parts.

Emersed plants are rooted in bottom muds and produce a majority of their leaves and flowers at or above the water surface. Some species have leaves that are flat and float entirely upon the water surface. Other species have leaves that are saucer-shaped or whose margins are irregular or fluted. The latter types of leaves do not float entirely upon the water surface.

Marginal plants are probably the most widely distributed of the rooted aquatic plants. Members of this group are varied in size, shape, and preference of habitat. Many species are adapted for growth from moist soils into water up to 2 feet deep or more. Other species are limited to moist soil or entirely to a watery habitat.

There are some species of floating plants that are rather limited in their distribution while others are widespread throughout the world. Plants in this group have true roots and leaves, but instead of being anchored in the soil they float about on the water surface. Buoyancy of the plant is accomplished through modification of the leaf (including covering of the leaf surface) and leaf petiole. Most species have well-developed root systems which collect nutrients from the water.

Species designated as weeds are not necessarily such in all places and at all times. For example, many submersed, floating, and emersed plants that normally interfere with boating, swimming, and fishing are regarded as desirable growths in waterfowl refuge areas. Rooted plants with floating leaves, such as water lillies and watershield, and those that float upon the surface, such as water hyacinth, elodea, parrotweed, alligatorweed, and duckweed, are considered highly objectionable for many water uses. In clear water areas, however, where artificial or natural fertilization is moderate, the removal of these surface-shading plants may permit sunlight to penetrate to the bottom muds and submersed plants soon will occupy these waters. These submersed plants generally are more objectionable in an area than the original surface-covering plants.

Most emersed, marginal, and a few submersed plants and filamentous algae produce growths that provide a suitable habitat for the development of anopheline and other pest-type mosquitoes as well as a hiding place for snakes. They are excellent habitats for damselflies and some aquatic beetles.

Most rooted and floating aquatic plants can seriously interfere with navigation of small recreational craft and large commercial boats in infested areas. Such problems are prevalent in intercoastal waterways and in some streams in the Gulf States area. Water shortages due to consumption by undesirable aquatic plants or reduction in carrying capacity of an irrigation or drainage canal through excessive vegetation can result in decreased crop quality, yield, or even crop failure.

Submersed and emersed weeds consume nutrients, either available or added, that could otherwise be used to grow desirable planktonic algae in impounded waters. Thus, the presence of excessive rooted plants may reduce total fish production in the infested body of water. Extensive growth of weeds provides dense cover that allows the survival of excessive numbers of fish resulting in overcrowding and stunting as well as interfering with harvesting the fish by hook and line or other methods. There is evidence that rank growths of submersed, emersed, or floating weeds may deplete the dissolved oxygen supply in shallower water and that fish tend to leave these areas if there are open-water areas available of better quality. Although they carry on the process of photosynthesis, their multicellular structure often makes them less effective in re-oxygenating the water.

All the elements essential for plant growth are yet to be determined. Some of the elements known to be important are nitrogen, phosphorus, potassium, magnesium, calcium, manganese, iron, silicon (for diatoms), sulfur (as sulfates), oxygen, and carbon. In many habitats, abundance of the first two elements, N (nitrogen) and P (phosphorus), promotes vegetative production if other conditions for growth are favorable. Most algae also require some simple organics, such as amino acids and vitamins, and many trace elements, such as manganese and copper. Not only are the various factors important, but their relative abundance and combined affect can be of even greater importance. Limited laboratory studies made to date indicate that different species of algae have somewhat different phosphorus requirements with the range of available phosphorus usually falling between 0.01 and 0.05 mg/l as phosphorus. At these levels, when other conditions are favorable, blooms may be expected. As has been pointed out by the Subcommittee on Water Quality Criteria for Public Water Supply, the total phosphorus is of outstanding importance. While there is no set relationship between total and available phosphorus (because the ratio varies with season, temperature, and plant growth), the total phosphorus is governing as it is the reservoir that supplies the available phosphorus. It is believed that allowable total phosphorus depends upon a variety of factors; e.g., type of water, character of bottom soil, turbidity, temperature, and especially desired water use. Allowable amounts of total phosphorus will vary, but in general it is believed that a desirable guideline is 100 µg/l for rivers and 50 µg/l where streams enter lakes or reservoirs (recommended by the Public Water Supply Subcommittee).

The nitrogen-phosphorus ratio is also of importance. The ratio varies with the water, season, temperature, and geological formation, and may range from 1 or 2:1 to 100:1. In natural waters, the ratio is often very near 10:1, and this appears to be a good guideline for indicating normal conditions.

The major sources of nitrogen entering fresh waters are atmospheric (approximately 5 lbs/acre/year), (Hutchinsen, 1957), domestic sewage effluents, animal and plant processing wastes, animal manure, fertilizer and chemical manufacturing spillage, various types of industrial effluents, and agricultural runoff.

The major sources of phosphorous entering fresh waters are domestic sewage effluents (including detergents), animal and plant processing wastes, fertilizer and chemical manufacturing spillage, various industrial effluents, and, to a limited extent, erosion materials in agricultural runoff.

Phosphorous entering an ecosystem may produce a high oxygen demand. It has been pointed out that 1 milligram of phosphorous from an organic source demands about 160 milligrams of oxygen in a single pass through the phosphorus cycle to complete oxidation. Thus the oxidation of organic matter, the growth of which has been induced by adding phosphorus, may bring about a great reduction of oxygen in a lake or stream.

Dissolved carbon in the form of simple organic compounds can be utilized by many kinds of algae. These types of carbon compounds are also used directly as a source of food by many animals. Varying amounts of simple organic compounds containing carbon are found in sewage and several types of industrial wastes. Other more complex forms of organic carbon can be utilized by bacteria. The most common nuisance growth that becomes very abundant in the presence of very small amounts of carbon is *Sphaerotilus*. Patrick (unpublished data) has shown that the addition of 0.05–0.1 mg/l of glucose, without changing other ecological conditions, may produce nuisance growths.

Knowledge of the nutrient requirements of fungi, phytoplankton, and filamentous algae is more extensive than for rooted aquatic plants. Laboratory data on nutrient requirements must be used with caution, however, because the maintenance of most long-term cultures has required that extracts of soil be incorporated into the inorganic culture medium. Analyses of field grown algae have indicated a wide divergence in elemental composition among various species and among the same species from different localities. Excessive growths often seen to be triggered by small amounts of so-called minor or trace elements and vitamins, particularly B_{12}.

One of the most obvious effects of increases or imbalances in nutrients is the change in the kinds and abundance of species composing the algal flora. Historical studies of Lake Erie show a change from an *Asterionella* dominance in the spring and a *Synedra* dominance in the fall of 1920 to a *Melosira* dominance in the spring and a *Melosira, Anabaena, Oscillatoria* dominance in the fall of 1962. Between 1919 and 1934, the number of cells per ml, with two exceptions, always were less than 4,000/ml. Since 1934, the cell count, with one exception, has always been greater than 4,000/ml. In 1944, it reached 11,032 cells/ml. It should be pointed out that blue-green algae are a poor source of food for most aquatic life.

Benthic forms also indicate the increase in nutrients in an ecosystem. Various species of *Cladophora* become abundant in lakes and rivers when nutrients are abundant and replace the original diverse benthic flora.

This demand for a wide variety of nutrients is also characteristic of many of the rooted aquatic plants. Their affinity for numerous metals, however, does not appear to be comparable to that of the algae.

Extensive data exist on the concentration of nitrogen and phosphorus in fresh waters throughout the United States. (Allee, et al., 1949; Ellis, 1940; Engelbrecht and Morgan, 1961; Juday, et al., 1927; Lackey, 1945; USDHEW, 1962a) In evaluating these data, it must be remembered that algae and most other aquatic plants are capable of utilizing any available N and/or P in a very short time providing other growth conditions are favorable. Thus, analyses of filtered water would not provide an evaluation of all elements existing in the original water sample. A more meaningful figure would result if all materials in an original water sample were digested and then analyzed. Often, the dissolved or available phosphorus may be very low, while the total amount in the organisms and organic matter may be quite large. Not only does this determination of total phosphorous give a better estimate of the existing nutrient load of an area, but it also provides an index to the potential release that would occur if these plants should all die within a short period of time.

This information would also point out the fact that in many freshwaters, various species of rooted aquatic plants are excellent receptors for this nutrient load. Their use in effluent treatment might be one of the cheaper waste-treatment procedures. The chemical composition of several species of plants is given in table III–4. Indications are that the N–P content of freshwaters in the United States is quite varied, and their presence in fairly large amounts may or may not produce algae blooms.

It must be remembered that factors other than plant nutrients also are operative in the establishment and maintenance of aquatic plant growths. There must be sufficient light reaching the plant for photosynthesis to occur. If turbidity from muds, dyes, other materials, or even phytoplankton is too great, plants at lower depths cannot grow. These same plants, however, if established in an area, can trap large amounts of intermittent silt and other materials and clear the waters for downstream uses.

Another factor that might be operative in preventing aquatic plant growth would be the lack of free CO_2 and bicarbonate ions in a particular aquatic environment. Certainly in an area where the pH is high (9.5 or above) or low (below 5.5), productivity would not reach high levels due to a lack of sufficient bicarbonates.

Temperature also is an important factor in determining the amount of growth. For each species, there is an optimum range in which the greatest growth occurs.

Wave action on large expanses of water may also be a factor in regulating all types of aquatic plant growths. This appears contradictory to the concept that winds cause mixing of surface and bottom waters, thereby renewing plant nutrients in the euphotic zone. However, in certain lakes and reservoirs, wind-induced waves and currents mechanically agitate bottom materials and waters to an extent that interferes with the production of phytoplankton and rooted aquatic plants.

Various workers have discussed the concentrations of nitrogen and phosphorus that are needed for an algal bloom. Sawyer (1947) suggests that a concentration of at least 15 μg/l of phosphorus is necessary for growth. Hutchinson (1957) states that *Asterionella* can take up phosphorus from where it is present at less than one μg/l. As a result of the study of 17 Wisconsin lakes, Mackenthun (1965) cites results indicating that inorganic nitrogen at 0.30 mg/l and inorganic phosphorus at 0.01 mg/l, at the start of an active growing season, subsequently permitted algal blooms. As yet, there is no definite information on the amount of wastes that will produce predictable harmful effects in a lake. There are indicators, however, of developing or potentially undesirable conditions.

There are several conditions, analyses, or measures that will indicate eutrophication and dystrophication. Since these parameters are not infallible, it is well to use them in combinations. Conditions indicative of organic enrichment are:

(1) A slow overall decrease year after year in the dissolved oxygen in the hypolimnion as indicated by determinations made a short time before the fall overturn and an increase in anaerobic areas in the lower portion of the hypolimnion.

TABLE III–4. Chemical Composition of Some Algae From Ponds and Lakes in Southeastern United States[1]

Analysis	Chara	Pithophora	Spirogyra	Giant Spirogyra	Rhizoclonium	Oedogonium	Mougeotia	Anabaena
Ash percent	43.4	27.77	13.06	13.86	17.36	12.69	14.54	5.19
C percent	29.3	35.38	42.40	41.16	39.10	40.84	40.74	49.70
N percent	2.46	2.57	3.01	2.35	3.46	2.64	1.77	9.43
P percent	0.25	0.30	0.20	0.23	0.43	0.08	0.25	0.77
S percent	0.55	1.42	0.27	[illegible]	0.27	0.15	0.36	0.53
Ca percent	8.03	3.82	0.57	0.84	0.52	0.44	1.68	0.36
Mg percent	0.92	0.70	0.45	0.30	0.21	0.16	0.57	0.42
K percent	2.35	3.06	0.92	0.99	1.93	3.03	1.20	1.20
Na percent	0.13	0.07	1.42	1.43	0.09	0.06	0.49	0.18
Fe mg/l	2,520	2,336	1,368	1,793	1,820	1,645	60	80
Mn mg/l	2,926	829	1,641	1,658	1,667	1,729	1,080	800
Zn mg/l	89	29	72	46	89	119	520	...
Cu mg/l	19	23	47	34	75	75	143	70
B mg/l	6.7	65	4.2	4.3	1.8	8.1	8	...

Analysis	Cladophora	Euglena	Hydrodictyon	Microcystis	Lyngbya	Nitella	Aphanizomenon
Ash percent	23.38	4.12	17.94	6.2	17.20	19.11	7.21
C percent	35.27	48.14	39.96	46.46	40.23	38.43	47.65
N percent	2.30	5.14	3.87	8.08	5.01	2.70	8.57
P percent	0.56	0.67	0.24	0.68	0.31	0.23	1.17
S percent	1.58	0.19	1.41	0.27	0.28	0.34	1.18
Ca percent	1.69	0.05	0.69	0.53	0.45	1.89	0.73
Mg percent	0.23	0.07	0.17	0.17	0.14	0.95	0.21
K percent	6.08	0.34	4.21	0.79	0.42	3.73	0.68
Na percent	0.18	0.02	0.38	0.04	0.06	0.28	0.19
Mn mg/l	1,040	240	1,373	2,751	5,230	2,388	167
Fe mg/l	2,300	1,545	1,963	322	3,866	2,180	833
Zn mg/l	10	73	129	48	171	240	120
Cu mg/l	190	290	114	37	101	39	187
B mg/l	84.6	3.8	...	3.6	112	9.8	...

[1] Lawrence (personal communication).

(2) An increase in dissolved solids—especially nutrient materials such as nitrogen, phosphorus, and simple carbohydrates.

(3) An increase in suspended solids—especially organic materials.

(4) A shift from a diatom-dominated plankton population to one dominated by blue-green and/or green algae, associated with increases in amounts and changes in relative abundance of nutrients.

(5) A steady though slow decrease in light penetration.

(6) An increase in organic materials and nutrients, especially phosphorus, in bottom deposits.

Recommendation: The Subcommittee wishes to stress that the concentrations set forth are suggested solely as guidelines and the maintenance of these may or may not prevent undesirable blooms. All the factors causing nuisance plant growths and the level of each which should not be exceeded are not known.

(1) In order to limit nuisance growths, the addition of all organic wastes such as sewage, food processing, cannery, and industrial wastes containing nutrients, vitamins, trace elements, and growth stimulants should be carefully controlled. Furthermore, it should be pointed out that the addition of sulfates or manganese oxide to a lake should be limited if iron is present in the hypolimnion as they may increase the quantity of available phosphorus.

(2) Nothing should be added that causes an increased zone of anaerobic decomposition of a lake or reservoir.

(3) The naturaily occurring ratios and amounts of nitrogen (particularly NO_3 and NH_4) to total phosphorus should not be radically changed by the addition of materials. As a guideline, the concentration of total phosphorus should not be increased to levels exceeding 100 $\mu g/l$ in flowing streams or 50 $\mu g/l$ where streams enter lakes or reservoirs.

(4) Because of our present limited knowledge of conditions promoting nuisance growth, we must have a biological monitoring program to determine the effectiveness of the control measure put into operation. A monitoring program can detect in their early stages the development of undesirable changes in amounts and kinds of rooted aquatics and the condition of algal growths. With periodic monitoring such undesirable trends can be detected and corrected by more stringent regulation of added organics.

Toxic substances

Aquatic life too frequently is considered only in terms of harvestable species. The fact that numerous other organisms are essential to produce a crop of fishes often is overlooked or given little attention. To produce a harvestable crop of fish, it is essential to have supporting plants and animals for food. Requirements are established on the basis that the needed criteria are those that will protect fish, the harvested crop, and the food organisms necessary to support that crop. At this time, it is believed that every important species should be protected. One can appreciate that unimportant organisms may be sacrificed if the following criteria are adopted. Fish too often are considered as a single species instead of a multitude of species. Many are distinctly and greatly different from other related species and have their own distinctive requirements. Because of this, and because the important species, *essential* food organisms, and water quality will be different in different habitats, a single value or concentration has very limited applicability unless appropriate margins of safety are incorporated.

For these reasons, the bioassay approach described later in this section is favored. It is believed that bioassays are the best method for determining safe concentrations of toxicants for the species of local importance. Bioassays are essential also to determine safe concentrations for food organisms of those species and the effect of existing water quality, including environmental variables as well as existing pollution. Pertinent to this stance is the fact that the majority of specific pollution problems are ones involving discharges of unknown and variable composition. Almost without exception, more than one toxicant or stress is present. Further, suggested safe concentrations probably will not be adequate in instances where more than one adverse factor exists. It is believed that these recommended levels will be adequate for a particular pollutant if dissolved oxygen, temperature, and pH are within the limits recommended. If the latter parameters are outside recommended limits, appropriate alterations in the criteria for toxicants must be made.

Most of the available toxicity data are reported as the median tolerance limit (TL_m), the concentration that kills 50 percent of the test organisms within a specified time span, usually in 96 hours or less. This system of reporting has been misapplied by some who have erroneously inferred that a TL_m value is a safe value, whereas it is merely the level at which half the test organisms are killed. In many cases, the differences are great between TL_m concentrations and concentrations that are low enough to permit reproduction and growth.

Substantial data on long-term effects and safe levels are available for only a few toxicants, perhaps 10. The effect of toxicants on reproduction is nearly unknown, yet this is a very important aspect of all long-term toxicity tests. In chronic tests with six different toxicants, there were three toxicants with which certain concentrations permitted indefinite survival and normal appearance but blocked spawning completely. Such evidence makes estimates of safe concentrations based on acute lethal test data alone very difficult and frequently erroneous. Equally problematical is the near-total lack of information on the sensitivity of the various life stages of organisms. Many organisms are the most sensitive in the larval, nymph, molting, or fry state; some may be the most sensitive in the egg and sperm stage.

A further difficulty is encountered in recommending criteria because continuous acceptable concentrations must be lower than the intermittent concentrations that may be reached occasionally without causing damage. There seems to be only one way in which to resolve this difficulty and that is to use *both* maximum concentration and a range of concentrations. It is recognized that the extremes do limit organisms, but, within these extremes there is a range in concentration that can be tolerated and is safe for prolonged periods of exposure.

Average 24-hour concentrations can be determined by using a small water pump to collect 1 to 5 ml samples every minute. After 24 hours, the sample is mixed and analyzed. The concentration found represents the average concentration. Samples obtained this way are more reproducible and easier to secure than the maximum instantaneous concentration. Maximum concentrations must be considered in the criteria, however, because an average concentration alone could be met and yet permit a lethal concentration to exist for a critical period.

Bioassay

The use of some type of bioassay to determine the toxicity of a material or waste can be the most effective and accurate method of assessing potential danger. With these methods, no assumptions need be made concerning the chemical structure or form of the pollutant, nor does the investigator have to know the constituent substances. The effects of water quality on toxicity also may be measured. Naturally, the more that is known about the chemical and physical behavior of a toxicant in water, the more precise the assay can be.

While there are many types of assays, two are in general use: (1) the static bioassay in which the test solution is not changed during the period of exposure, and (2) the flow-through bioassay in which the test solution continually is renewed. It is nearly impossible in a static test to use the introduced test concentration for calculating TL_m values, especially for substances or wastes that are toxic at concentrations of 1 mg/l or less, because the quantity taken into the test organism may be a very large percentage of the amount contained in the test water. A 48-hour TL_m based on the introduced concentration could give a value much higher than the true concentration because of this decrease in toxicant concentration. The initial test concentration is usually not measured in static tests because of the changing concentration. Knowledge of the concentration of the toxicant at the end of the test can be of value.

The static test can give useful relative measures of toxicity for wastes of high toxicity, but for the reason mentioned above, it should not be used for absolute values. Less toxic substances can be assayed much more accurately and lethal concentrations can be determined with confidence. The chemical nature of the tested substances has an important effect on the accuracy of the results as well. Substances that are volatile, unstable, or relatively insoluble may not be accurately assayed while substances having opposite properties can be assayed more accurately.

The problem of maintaining oxygen concentrations suitable for aquatic life in the test chamber can be very difficult. Insufficient oxygen may be present in the test water volume because a BOD or COD may consume much of the available dissolved oxygen and aeration or oxygenation may degrade or remove the test material. Devices for maintaining satisfactory dissolved oxygen in static tests have been proposed and used with some degree of effectiveness. A rather complete account of static assays can be found in Sandard Methods for the Examination of Water and Wastewater, 12th edition (1965), and Doudoroff, et al. (1951).

In the flow-through type of bioassay a device is used to add toxicant to a flow of water and the mixture is discharged into the test container. This method of testing has few of the problems mentioned in connection with the static test and has other advantages in addition. Its important disadvantage is the more complicated work of building the necessary equipment; namely, a water supply system, metering devices, and the provision of a large quantity of the test substance.

Its important advantages are that a predetermined concentration of test material can be maintained, oxygen concentrations can be kept high or be controlled, metabolites and waste products are removed (animals can be fed), absolute rather than relative TL_m values can be obtained, and volatile, unstable, and sparingly soluble materials can be tested. Additionally, multifactor experiments are possible in which several variables can be controlled (pH, dissolved oxygen, carbon dioxide, etc.). The constant renewal test is superior for monitoring effluents, water supplies, or streams on a continuous or intermittent basis and is the only suitable method for long-term tests.

Several systems for adding the test material to the water have been devised since this type of bioassay has been in use. Lemke and Mount (1963) describe a system using a controlled water flow balanced against a chemical metering pump. Henderson and Pickering (1963) describe a simple drip system and a controlled water flow; a similar system is proposed by Jackson and Brungs (1966). Both of these latter references describe the use of fish and flowing systems as continuous monitors. Mount and Warner (1965), Mount and Brungs (1967), and Brungs and Mount (1967) describe systems suitable for continuous short or long-term tests.

Most criteria for toxic substances must be based on a bioassay made for each specific situation. This is dictated by the lack of information and the wide variation in situations, species, water quality, and the nature of the substance being added to the water.

Most of the bioassay work on algae has measured the threshold concentrations that reduce physiological processes by 50 percent rather than the concentrations that cause 50-percent death in the population tested. It is very difficult to determine the death point of algae cells, but some workers have used it as a criterion. Physiological measurements have been based largely on 50-percent reduction in photosynthesis and 50-percent reduction in number of divisions that have taken place during a period of time. This is determined by the number of cells present at the beginning and end of the experiment. A bioassay method employing diatoms has been recognized by the American Society for Testing Materials (1964).

Application Factors

Short-term or acute toxicity tests provide information on the overall toxicity of a material and thus precede meaningful long-term toxicity studies. They may also be used to compare toxicities of different materials. When water for dilution is taken from the receiving stream, these tests may also indicate additional stresses due to materials already present in the receiving water. These acute studies do not indicate concentrations of a potential toxicant that are harmless under conditions of long-term exposure. It is desirable, therefore, to develop a factor that can be used with 96 or 48-hour TL_m values to indicate concentrations of the waste or material in question that are safe in the receiving water. Such a factor has been called an application factor.

Ideally, an application factor should be determined for each waste or material. To do this, it would be necessary to determine the concentration of the waste or material in question that does not adversely affect the productivity of the aquatic biota on continuous exposure, in water of known quality, and under environmental conditions (DO, temperature, pH, etc.) at which it is most toxic. This concentration is then divided by the 96-hour TL_m value obtained under the same conditions to give the application factor.

$$\frac{\text{safe concentration for continuous exposure}}{\text{96-hour } TL_m}$$

For example, if the 96-hour TL_m is 0.5 mg/l and the concentration of the waste found to be safe is 0.01 mg/l, the application factor would be:

$$\frac{\text{safe concentration}}{\text{96-hour } TL_m} = \frac{0.01}{0.50} = \frac{1}{50}$$

In this instance, the application factor is $\frac{1}{50}$ or 0.02. Then in a given situation involving this waste, the safe concentration in the receiving stream would be found by multiplying the 96-hour TL_m by 0.02.

To effectively determine the application factor for a given waste, it is necessary to determine the concentration of that waste which is safe under a given set of conditions. For those materials whose toxicity is not significantly influenced by water quality and in streams free of other wastes that influence the waste in question or that have water qualities similar to those under which the waste was tested, the above-mentioned concentration would be the one that is safe in the receiving water. However, differences in water quality and lack of information on the toxicity of waste materials already present make the direct use of laboratory-determined safe levels unwise at present, and a different approach is recommended.

In this approach, a 96-hour TL_m is determined for the waste using water from the receiving stream for dilution and, as test organisms, the most sensitive species or life stage of an economically important local species or one whose relative sensitivity is known. This procedure would take into consideration the effects of local quality and the stress or adverse effects of wastes already present in the stream. The TL_m value thus found then is multiplied by the application factor for that waste to determine the safe concentration of that waste in that stream or stream section. Such bioassays should be repeated at least monthly and at each change in process or rate of waste discharge.

This procedure must be used because of the extreme difference in sensitivity among species and among necessary fish food organisms. Henderson (1957) has discussed various factors involved in developing application factors. Results of studies by Mount and Stephan (1967), in which continuous exposure was used, reveal that the application factor necessary to reduce the concentration low enough to permit spawning ranged from 1/7 to 1/500. It is recognized that exposure will not be constant in most cases and that higher concentrations usually can be tolerated for short periods.

At present, safe levels have been determined for only a few wastes and hence only a few application factors are known. Since the determination of safe levels is an involved process, it will be necessary to use indirect or stopgap procedures for estimating tolerable concentrations of various wastes in receiving waters. To meet this situation, it is proposed to use three universal application factors selected on the basis of present knowledge, experience, and judgment. It is proposed that these general application factors be applied to TL_m values determined by those discharging wastes in the manner described above to set tolerable concentrations of their wastes in the receiving stream.

It should be evident that when these general application factors are used for all wastes the resulting concentrations at times will be more stringent than needed for some wastes and inadequate for others. The derived concentrations will be tolerable, however, for a considerable number of wastes in the midrange of relative toxicity.

Recommendation for the Use of Bioassays and Application Factors To Denote Safe Concentrations of Wastes in Receiving Streams: (1) For the determination of acute toxicities, flow-through bioassays are the first choice. Methods for carrying out these flow-through tests have been described by Surber and Thatcher (1963), Lemke and Mount (1963), Henderson and Pickering (1963), Jackson and Brungs (1966), Mount and Warner (1965), Mount and Brungs (1967), and Brungs and Mount (1967). Flow-through bioassays should be used for unstable, volatile, or highly toxic wastes and those having an oxygen demand. They also must be used when several variables such as pH, DO, CO_2 and other factors must be controlled.

(2) When flow-through tests are not feasible, tests of a different type or duration must be used. The kinds of local conditions affecting the procedure might be a single application of pesticides or lack of materials and equipment.

(3) Acute static bioassays with fish for the determination of TL_m values should be carried out in accordance with Standard Methods for the Examination of Water and Wastewater, 12th edition (1965). Such tests should be used for the determination of TL_m values only for persistent, nonvolatile, or highly soluble materials of low toxicity which do not have an oxygen demand because it is necessary to consider the amount added as the concentration to which the test organisms are exposed.

(4) When application factors are used with TL_m values to determine safe concentrations of a waste in a receiving water, the bioassay studies to determine TL_m values should be made with the most sensitive local species and life stages of economical or ecological importance and with dilution water taken from the receiving stream above the waste outfall. Other species whose relative sensitivity is known can be used in the absence of knowledge concerning the most sensitive of the important local species or life stages or due to difficulty in providing them in sufficient numbers. Alternatively, tests may be carried out using one species of diatom, one species of an invertebrate, and two species of fish, one of which should be a pan or game fish. Further, these bioassays must be performed with environmental conditions at levels at which the waste is most toxic. Tests should be repeated with one of the species at least monthly and when there are changes in the character or volume of the waste.

(5) Concentration of materials that are nonpersistent (that is, have a half life of less than 96 hours) or have noncumulative effects after mixing with the receiving waters should not exceed 1/10 of the 96-hour TL_m value at any time or place. The 24-hour average of the concentration of these materials should not exceed 1/20 of the TL_m value after mixing. For other toxicants the concentrations should not exceed 1/20 and 1/100 of the TL_m value under the conditions described above. Where specific application factors have been determined, they will be used in all instances.

When two or more toxic materials whose effects are additive are present at the same time in the receiving water, some reduction in the permissible concentrations as derived from bioassays on individual substances or wastes is necessary. The amount of reduction required is a function of both the number of toxic materials present and their concentrations in respect to the derived permissible concentration. An appropriate means of assuring that the combined amounts of the several substances do not exceed a permissible concentration for the mixture is through the use of following relationship:

$$\left(\frac{C_a}{L_a}+\frac{C_b}{L_b}\cdots+\frac{C_n}{L_n}\leq 1\right)$$

Where C_a, C_b, . . . C_n are the measured concentrations of the several toxic materials in the water and L_a, L_b, . . . L_n are the respective permissible concentration limits derived for the materials on an individual basis. Should the sum of the several fractions exceed one, then a local restriction on the concentration of one or more of the substances is necessary.

Heavy Metals

An extensive discussion of the physiological mode of action of heavy metals is found in the toxicity portion of the section on water quality requirements for marine organisms.

Zinc: While much information has been published regarding zinc, a large amount of the data cannot be used because of incomplete description of methods, type of water, or concentrations. The authors of many of the papers dealing with zinc toxicity have used various specific sublethal effects as endpoints and there is no way to compare these findings with other work.

Since the concentration of calcium and magnesium influences heavy metal toxicity, permissible levels of heavy metals are dependent on the calcium and magnesium concentrations. Certain studies with zinc (Mount, 1966; and unpublished work of the FWPCA National Water Quality Lab., Duluth, Minn.) and cadmium indicate that for a given calcium and magnesium concentration the acute toxicity of zinc and cadmium increases (TL_m concentration decreases) as pH is raised from 5 to 9. This seems contrary to prevalent opinion that metal toxicity is related to metal in solution and that as pH increases (solubility decreases) the toxicity decreases. The reason for this apparent contradiction is that conceptions concerning the effect of pH are based on natural waters in which pH does not vary independently of calcium and magnesium concentrations, but rather is closely related to it. In those cases where this relationship has been studied, except for one (Sprague, 1964b), the toxicity has increased with an increase in pH. This concept also is consistent with the work of Lloyd (1961b) and, more recently, that of Herbert and Wakeford (1964) who concluded that colloidal or flocculated, but suspended, zinc exerts a toxic influence on fish.

The significance of temperature and the calcium-magnesium content on the toxicity of zinc to plankton has been pointed out by Patrick (unpublished data). In these tests, a 50-percent reduction in growth of the population was used as a measure. Results of these tests are summarized as follows:

Temperature of test solution	*Concentration in mg/l which reduces growth of population by 50 percent*	
	Ca-Mg concentration—44 mg/l as $CaCO_3$ **Nitzchia linearis**	*Ca-Mg concentration—170 mg/l as* $CaCO_3$ **Navicula seminulum**
72 F	4.29 mg/l	4.05 mg/l.
82 F	1.59 mg/l	2.31 mg/l.
86 F	1.32 mg/l	3.22 mg/l.

Palmer (1957) found that zinc dimethyl dithiocarbamate (ZDD) inhibited growth of *Microcystis* at 0.004 mg/l. A concentration of 0.25 mg/l controlled all diatoms, 43 percent of the blue-green algae, and 18 percent of the green algae. The above evidence implies that permissible levels of zinc cannot be related to the calcium-magnesium concentrations or to pH alone.

Herbert and Wakeford (1964) described the effect of salinity on the toxicity of zinc to rainbow trout. Since zinc was most toxic to trout in freshwater, it is assumed that concentrations which are safe in freshwater will be safe for the salmonids in brackish water. The maximum reported affect of a reduction of dissolved oxygen from 6–7 mg/l to 2 mg/l on the acute toxicity of zinc is a 50-percent increase in its acute toxicity (Lloyd, 1961a; Pickering, in press; Cairns and Scheier, 1958a). Since 4 mg/l is the minimum permitted, this effect is small in comparison to the difference between safe and acutely toxic concentrations. The use of an application factor, therefore, should provide adequate protection. Similarly, Herbert and Shurban (1963a) found that the 24-hour TL_m for zinc was reduced only 20 percent for rainbow trout forced to swim at 85 percent of their maximum sustained swimming speed.

The effect of calcium and magnesium concentrations on the toxicity of zinc for plankton, invertebrates, fishes, and their embryonic stages is reflected in the spread of values reported as toxic by many sources (Anderson 1950; Brungs, in press; Cairns and Scheier 1957, 1958b; Grande, 1966; Herbert and Shurben, 1963a, b; Jones, 1938; Lloyd, 1961b; Patrick, personal communication; Pickering, in press; Pickering and Henderson, 1966a; Pickering and Vigor, 1965; Skidmore, 1964; Sprague, 1964a, b; Sprague and Ramsey, 1965; Williams and Mount, 1965; and Wurtz, 1962).

Recommendation: The relationship between calcium and magnesium concentration, pH, and zinc toxicity is confusing and the separate effects have been little studied. Brungs (in press) has determined that $\frac{1}{100}$ of the 96-hour TL_m value is a safe concentration for continuous exposure.

Copper: The same general considerations apply to the determination of safe levels of copper as apply to safe levels for zinc and the discussion of copper will be based on the same assumptions. From the published data, differences in species sensitivity to copper appear to be somewhat greater than for zinc (Anderson, 1950; Grande, 1966; Herbert and Vandyke, 1964; Jones, 1938; Lloyd, 1961b; Mount, in press; Pickering and Henderson, 1966a; Sprague, 1964a, b; Sprague and Ramsey, 1965; Trama, 1954; Turnbull, DeMann, and Weston, 1954). Mount (in press) has found that $\frac{1}{30}$ of the 96-hour TL_m value is a safe concentration for continuous exposure of fish.

Bringmann and Kuhn (1959a, b) report that 0.15 mg/l copper is the threshold concentration which produces a noticeable effect on *Scenedesmus*. Maloney and Palmer (1956) report that 0.5

mg/l copper as copper sulfate produces the following percents of death in algae:

57 percent in 17 species of blue-green algae.
35 percent in 17 species of green algae.
100 percent in 6 species of diatoms.

Fitzgerald, Gerloff, and Borg (1952) report that 0.2 mg/l of copper (as copper sulfate) produces a 100-percent kill of *Microcystis aeruginosa.* Crance (1963) found 0.05 mg/l kills *Microcystis.* Hassall (1962), working with *Chlorella vulgaris* found that 25 g/l of copper sulfate did not inhibit respiration if cultures were shaken. If shaking stopped, concentrations greater than 250 mg/l were toxic. Preliminary experiments indicate that lack of air increases toxicity of copper. Hale (1937)—according to Jordan, Day, and Hendrixson (1962)—reported that the following concentrations were necessary to control the indicated algae:

0.5 mg/l—*Cladophora.*
0.1 mg/l—*Hydrodictyon.*
0.12 mg/l—*Spirogyra.*
0.20 mg/l—*Ulothrix.*

Calcium and magnesium concentrations are usually not given for algal tests, but it would seem that the concentrations deemed safe for fish would also be acceptable for plankton.

Recommendation: The maximum copper (expressed as Cu) concentration (not including copper attached to silt particles or in stable organic combination) at any time or place should not be greater than $\frac{1}{10}$ the 96-hour TL$_m$ value, nor should any 24-hour average concentration exceed $\frac{1}{30}$ of the 96-hour TL$_m$ value.

Cadmium: Few studies have been made of the toxicity of cadmium in the aquatic environment. Mammalian studies have shown it to have substantial cumulative effects. Permissible levels in drinking water are 0.01 mg/l (USDHEW, 1962b), and concentrations of a few μg/g in food (McKee and Wolf, 1963) have caused sickness in human beings. Mount (1967) found accumulations in living bluegills as high as 100 μg/g (dry weight) and in the gills of dead catfish up to 1000 μg/g. Little accumulation was found in the muscle. Consideration should be given to acceptable residue levels in fish when establishing cadmium criteria.

Daphnia appears to be very sensitive to cadmium (Anderson, 1950). Bringmann and Kuhn (1959a) indicate *Scenedesmus,* and *Escherichia coli* are about equally sensitive. Data as yet unpublished (Pickering, in press) reveal that following prolonged exposure there is a large accumulation of cadmium in fish. Even though very little data are available yet, the evidence warrants a more restrictive requirement for cadmium than specified under the general bioassay section.

Recommendation: The concentration of cadmium must not exceed $\frac{1}{30}$ of the 96-hour TL$_m$ concentration at any time or place and the maximum 24-hour average concentration should not exceed $\frac{1}{500}$ of the 96-hour TL$_m$ concentration.

Hexavalent Chromium: The chronic toxicity of hexavalent chromium to fish has been studied by Olson (1958) and Olson and Foster (1956, 1957). Their data demonstrate a pronounced cumulative toxicity of chromium to trout and salmon. Mr. P. A. Olson (personal communication) of Battelle Memorial Institute advises that some recent comparisons of 48 and 96-hour TL$_m$ concentrations with concentrations not adversely affecting the same species indicate that the application factor for hexavalent chromium is $\frac{15}{100,000}$ for salmon and $\frac{6}{100,000}$ for rainbow trout. He also feels however, that such factors are not valid for carp. Doudoroff and Katz (1953) found that bluegills tolerated a 45 mg/l level for 20 days in hard water. Cairns (1956), using chromic oxide (CrO_3), found that a concentration of 104 mg/l was toxic in 6 to 84 hours. *Daphnia* and *Microregma* exhibit threshold effects at hexavalent chromium levels of 0.016 to 0.7 mg/l.

Some data are available concerning the toxicity of chromium to algae. The concentrations of chromium that inhibit growth (Hervey, 1949) for the test organisms are as follows: Chlorococcales, 3.2 to 6.4 mg/l; Euglenoids, 0.32 to 1.6 mg/l; and diatoms, 0.032 to 0.32, mg/l. Chromium at sublethal doses sometimes stimulates algae. Patrick (unpublished data) has studied the effects of temperature on the toxicity of chromium to certain algae. Her findings on the concentrations which reduce population growth by 50 percent are as follows:

Nitzschia linearis.—50 percent reduction in growth of population as compared with control (soft water 44 mg/l Ca-Mg as $CaCO_3$)

22 C—0.208 mg/l Cr
28 C—0.261 mg/l Cr
30 C—0.272 mg/l Cr

Navicula seminulum var. hustedtii (hard water 170 mg/l Ca-Mg as $CaCO_3$)

22 C—0.254 mg/l Cr
28 C—0.343 mg/l Cr
30 C—0.433 mg/l Cr

Recommendation: Data are too incomplete to do more than urge caution in the discharge of chromium. Concentrations of 0.02 mg/l in soft water have been found safe for salmonid fishes.

TABLE III–5A. Pesticides *

INSECTICIDES

[48-hour TL_m values from static bioassay, in micrograms per liter. Exceptions are noted.]

Pesticide	Stream invertebrate[1] Species	TL_m	Cladocerans[2] Species	TL_m	Fish[3] Species	TL_m	Gammarus lacustris,[4] TL_m
Abate	Pteronarcys californica.	100	------	----	Brook trout	1,500	640
Aldrin[5]	P. californica	8	Daphnia pulex.	28	Rainbow trout.	3	12,000
Allethrin	P. californica	28	D. pulex	21	do	19	20
Azodrin	------	----	------	----	do	7,000	----
Aramite	------	----	D. magna	345	Bluegill	35	100
Baygon[5]	P. californica	110	------	----	Fathead	25	50
Baytex[5]	P. californica	130	Simocephalus serrulatus.	3.1	Brown t.	80	70
Benzene hexachloride (lindane).	P. californica	8	D. pulex	460	Rainbow t.	18	88
Bidrin	P. californica	1,900	D. pulex	600	do	8,000	790
Carbaryl (sevin)	P. californica	1.3	D. pulex	6.4	Brown t.	1,500	22
Carbophenothion (trithion).	------	----	D. magna	0.009	Bluegill	225	28
Chlordane[5]	P. californica	55	S. serrulatus	20	Rainbow t.	10	80
Chlorobenzilate	------	----	S. serrulatus	550	do	710	----
Chlorthion	------	----	D. magna	4.5	------	----	----
Coumaphos	------	----	D. magna	1	------	----	0.14
Cryolite	------	----	D. pulex	5,000	Rainbow t.	47,000	----
Cyclethrin	------	----	D. magna	55	------	----	----
DDD (TDE)[5]	P. californica	1,100	D. pulex	3.2	Rainbow t.	9	1.8
DDT[5]	P. californica	19	D. pulex	0.36	Bass	2.1	2.1
Delnav (dioxathion)	------	----	------	----	Bluegill	14	690
Delmeton (systex)	------	----	------	14	do	81	----
Diazinon[5]	P. californica	60	D. pulex	0.9	do	30	500
Dibrom (naled)	P. californica	16	D. pulex	3.5	Brook t.	78	160
Dieldrin[5]	P. californica	1.3	D. pulex	240	Bluegill	3.4	1,000
Dilan	------	----	D. magna	21	do	16	600
Dimethoate (cygon).	P. californica	140	D. magna	2,500	do	9,600	400
Dimethrin	------	----	------	----	Rainbow t.	700	----
Dichlorvos[5] (DDVP)	P. californica	10	D. pulex	0.07	Bluegill	700	1
Disulfoten (di-syston)	P. californica	18	------	----	do	40	70
Dursban	Peteronareella badia	1.8	------	----	Rainbow t.	20	0.4
Endosulfan (thiodan)	P. californica	5.6	D. magna	240	do	1.2	64
Endrin[5]	P. californica	0.8	D. pulex	20	Bluegill	0.2	4.7
EPH	------	----	D. magna	0.1	do	17	36
Ethion	P. californica	14	D. magna	0.01	do	230	3.2
Ethyl guthion[5]	------	----	D. pulex	----	Rainbow t.	----	----
Fenthion	P. californica	39	D. pulex	4	------	----	----
Guthion[5]	P. californica	8	D. magna	0.2	Rainbow t.	10	0.3
Heptachlor[5]	P. badia	4	D. pulex	42	do	9	100
Kelthane (dicofel)	P. californica	3,000	D. magna	390	do	100	----
Kepone	------	----	------	----	do	37.5	----
Malathion[5]	P. badia	6	D. pulex	1.8	Brook t.	19.5	1.8
Methoxychlor[5]	P. californica	8	D. pulex	0.8	Rainbow t.	7.2	1.3
Methyl parathion[5]	------	----	D. magna	4.8	Bluegill	8,000	----
Morestan	P. californica	40	------	----	do	96	----
Ovex	P. californica	1,500	------	----	do	700	----
Paradichlorobenzene	------	----	------	----	Rainbow t.	880	----
Parathion[5]	P. californica	11	D. pulex	0.4	Bluegill	47	6
Perthane	------	----	D. magna	9.4	Rainbow t.	7	----
Phosdrin[5]	P. californica	9	D. pulex	0.16	do	17	310
Phosphamidon	P. californica	460	D. magna	4	do	8,000	3.8
Pyrethrins	P. californica	64	D. pulex	25	do	54	18
Rotenone	P. californica	900	D. pulex	10	Bluegill	22	350
Strobane[5]	P. californica	7	------	----	Rainbow t.	2.5	----
Tetradifon (tedion)	------	----	------	----	Bluegill	1,100	140
TEPP[5]	------	----	------	----	Fathead	390	52
Thanite	------	----	D. magna	450	------	----	----
Thimet	------	----	------	----	Bluegill	5.5	70
Toxaphene[5]	P. californica	7	D. pulex	15	Rainbow t.	2.8	70
Trichlorofon (dipterex).[5]	P. badia	22	D. magna	8.1	do	160	60
Zectran	P. californica	16	D. pulex	10	do	8,000	76

* See notes following Table III-5B.

Pesticides

A general description of the use and the effects of pesticides on aquatic life is given in the marine section. Basically, their effects are similar in both the marine and fresh water environments.

The addition of any persistent chlorinated hydrocarbon pesticides is likely to result in damage to aquatic life. Therefore, as concentrations of these chemicals increase in the aquatic environment, progressive damage will result. The acute effects usually will be recognized, but the chronic consequences may not be observed for some time.

The use of other kinds of chemical pesticides in or around fresh waters may produce a variety of acute and chronic effects on fish and the other components of the biota. Because these other chemicals are usually not as persistent as the chlorinated hydrocarbons, the Subcommittee feels some of them can be used around water, but only in amounts below those that produce chronic damage to desirable species.

Recommendation: (1) *Chlorinated hydrocarbons.*—Since any addition of persistent chlorinated hydrocarbon insecticides in likely to result in permanent damage to aquatic populations, their use should be avoided.

(2) *Other chemical pesticides.*—Addition of other kinds of chemicals used as insecticides, herbicides, fungicides, defoliants, acaracides, algicides, etc., can result in damage to some organisms. Table III–5 lists the 48-hour TL_m values for a number of pesticides for various types of fresh water organisms. To provide reasonably safe concentrations of these materials in receiving waters, application factors ranging from 1/10 to 1/100 should be used with these values depending on the characteristic of the pesticide in question and used as specified earlier in the section on application factors. Concentrations thus derived tentatively may be considered safe under the environmental conditions recommended.

Other Toxic Substances

Detergents and Surfactants: The toxicity of ABS has been reported by many workers. A wide range of endpoints have been used as criteria and while comparison is difficult, a reasonable conclusion is possible. There is no agreement on the effect of calcium and magnesium concentration. Recommendations are based on the data from table III–6.

Recommendation: With continuous exposure, the concentration of ABS should not exceed 1/7 of the 48-hour TL_m concentration. Concentrations as high as 1 mg/l may be tolerated infrequently for periods not exceeding 24 hours. ABS may increase the toxicity of other materials.

Much less work has been done on LAS, a newer, degradable detergent, than on ABS. Bardach, Fujiya, and Holl (1965) report that 10 mg/l is lethal to bullheads and 0.5 mg/l will erode 50 percent of the taste buds within 24 days. For fathead minnow fry, Pickering (1966) reports a 9-day TL_m of 2.3 mg/l. Thatcher and Santner (1967) report 96-hour TL_m values from 3.3 to 6.4 mg/l for five fish species. Swisher, O'Rourke, and Tomlinson (1954), testing bluegills, found TL_m values of 3 mg/l for LAS and 12 carbon homologs and 0.6 mg/l for 14 other carbon homologs. An intermediate degradation product had a TL_m of 75 mg/l. Dugan (1967) found that sensitivity to chlorinated pesticides possibly increased after exposure to detergent. Other studies as yet unpublished indicate a surprising increase in toxicity at low dissolved oxygen concentrations.

Pickering and Thatcher (in press), in the only reported study on reproduction, found that 0.6 mg/l had no measurable effect on reproduction or growth but 1.1 mg/l had an effect. In tests with five species of fishes. Thatcher and Santner (1967) found two species which were more sensitive to LAS than fathead minnows.

With both ABS and LAS detergents, the more readily degradable components are the more toxic. As a result, the components remaining will be less toxic than the original product.

Recommendation: The concentration of LAS should not exceed 0.2 mg/l of 1/7 of the 48-hour TL_m concentration, whichever is the lower.

Cyanide: Although it has been studied extensively, cyanide is not well understood as a hazard to aquatic life. Certain unique and peculiar characteristics necessitate special treatment of this chemical even though acceptable concentrations cannot be given.

Recent work on fish by Doudoroff et al. (1966), has demonstrated that HCN rather than CN is the toxic component. Except for certain extremely toxic heavy metals (silver, for example) the toxicity of metallo-cyanide complexes can also be attributed to the HCN. This then makes the effect of pH on cyanide toxicity of great importance. Doudoroff (1956) demonstrated a thousandfold increase in the toxicity of a nickelo-cyanide complex associated with a drop in pH from 8.0 to 6.5. A change in pH from 7.8 to 7.5 increases the toxicity ten times. The data reported by Cairns and Scheier (1963b) indicate that the calcium-magnesium concentrations (hardness) do not materially affect cyanide toxicity. It should be noted that in their test solutions while the calcium-magnesium concentration of their soft and hard

TABLE III-5B. Pesticides, cont.

HERBICIDES, FUNGICIDES, DEFOLIANTS, ALGICIDES

Pesticide	Stream invertebrate[1]		Cladocerans[2]		Fish[3]		Gammarus lacustris,[4]
	Species	TL_m	Species	TL_m	Species	TL_m	TL_m
Ametryne	------	------	------	------	Rainbow t.	3,400	------
Aminotriazole	------	------	------	------	------	------	------
Aquathol	------	------	------	------	Bluegill	257	------
Atrazine	------	------	Daphnia magna.	3,600	Rainbow t.	12,600	------
Azide, potassium	------	------	------	------	Bluegill	1,400	10,000
Azide, sodium	------	------	------	------	do	980	9,000
Copper chloride	------	------	------	------	do	1,100	------
Copper sulfate	------	------	------	------	do	150	------
Dichlobenil	Pteronarcys californica.	44,000	Daphnia pulex.	3,700	do	20,000	1,500
2,4-D, PGBEE	------	------	D. pulex	3,200	Rainbow t.	960	1,800
2,4-D, BEE	P. californica	1,800	------	------	Bluegill	2,100	760
2,4-D, isopropyl	------	------	------	------	do	800	------
2,4-D, butyl ester	------	------	------	------	do	1,300	------
2,4-D, butyl + isopropyl ester.	------	------	------	------	do	1,500	------
2,4,5-T isooctyl ester	------	------	------	------	do	16,700	------
2,4,5-T isopropyl ester	------	------	------	------	do	1,700	------
2,4,5-T PGBE	------	------	------	------	do	560	------
2(2,4-DP) BEE	------	------	------	------	do	1,100	------
Dalapon	P. californica Very low toxicity	------	D. magna	6,000	Very Low toxicity.		
Dead-X	P. californica	5,000	D. pulex	3,700	Rainbow t.	9,400	5,600
DEF	P. californica	2,300	------	------	Bluegill	36	230
Dexon	P. californica	42,000	------	------	Bluegill	23,000	6,000
Dicamba	------	------	------	------	non-tox.	------	5,800
Dichlone	------	------	D. magna	26	Rainbow t.	48	11,500
Difolitan	P. californica	150	------	------	Channel Cat.	31	6,500
Dinitrocresol	P. californica	560	------	------	Rainbow t.	210	------
Diquat	------	------	------	------	do	12,300	------
Diuron	P. californica	2,800	D. pulex	1,400	do	4,300	380
Du-ter	------	------	------	------	Bluegill	33	------
Dyrene	------	------	D. magna	490	------	15	------
Endothal, copper	------	------	------	------	Rainbow t.	290	------
Endothal, dimethylamine.	------	------	------	------	do	1,150	------
Fenac, acid	P. californica	70,000	------	------	do	16,500	------
Fenac, sodium	P. californica	80,000	D. pulex	4,500	do	7,500	18,000
Hydram (molinate)	P. californica	3,500	------	------	do	290	------
Hydrothol 191	------	------	------	------	do	690	1,000
Lanstan (korax)	------	------	------	------	do	100	5,500
LFN	------	------	------	------	do	79	------
Paraquat	P. californica Very low toxicity	------	D. pulex	3,700	Very low toxicity.	------	18,000
Propazine	------	------	------	------	Rainbow t.	7,800	------
Silvex, PGBEE	------	------	D. pulex	2,000	do	650	------
Silvex, isoctyl	------	------	------	------	Bluegill	1,400	------
Silvex, BEE	------	------	------	------	do	1,200	------
Simazine	P. californica	50,000	------	------	Rainbow t.	5,000	21,000
Sodium arsenite	P. californica Very low toxicity	------	Simocephalus serrulatus.	1,400	do	36,500	------
Tordon (picloram)	------	------	------	------	do	2,500	48,000
Trifuralin	P. californica	4,200	D. pulex	240	do	11	5,600
Vernam[5] (vernolate)	------	------	------	------	do	5,900	25,000

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[1] Stonefly bioassay was done at Denver, Colo., and at Salt Lake City, Utah. Denver tests were in soft water (35 mg/l TDS), non-aerated, 60 F. Salt Lake City tests were in hard water (150 mg/l TDS), aerated, 48–50 F. Response was death.

[2] **Daphnia pulex** and **Simocephalus serrulatus** bioassay was done at Denver, Colo., in soft water (35 mg/l TDS), non-aerated, 60 F. **Daphnia magna** bioassay was done at Pennsylvania State University in hard water (146 mg/l TDS), non-aerated, 68 F. Response was immobilization.

[3] Fish bioassay was done at Denver, Colo., and at Rome, N.Y. Denver tests were with 2-inch fish in soft water (35 mg/l TDS), non-aerated; trout at 55 F; other species at 65 F. Rome tests were with 2–2½-inch fish in soft water (6 mg/l TA: pH 5.85–6.4), 60 F. Response was death.

[4] **Gammarus** bioassay was done at Denver, Colo., in soft water (35 mg/l TDS), non-aerated, 60 F. Response was death.

[5] Becomes bound to soil when used according to directions, but highly toxic (reflected in numbers) when added directly to water.

water was greatly different, the pH and toxicity were similar.

Burdick and Lipschuetz (1950) show that some metallo-cyanide complexes decompose in sunlight and become highly toxic due to release of cyanide from the complex. Cairns and Scheier (1963b) found some increase in toxicity at reduced oxygen concentrations and Henderson, et al. (1961) demonstrated marked cumulative toxicity of an organic cyanide in 30-day tests.

The toxicity of cyanide to diatoms varied little with change of temperature and was a little more

TABLE III–6. Effect of Alkyl-Aryl Sulfonate, Including ABS, on Aquatic Organisms

Organisms	Concentration (mg/l)	Time	Effect	References
Trout	5.0	26 to 30 hours	Death	Wurtz-Arlet, 1960.
	3.7	24 hours	TL$_m$	
Bluegills	5.0		Gill pathology	Schmid and Mann, 1961.
	4.2	24 hours	TL$_m$	Turnbull, et al., 1954.
	3.7	48 hours	TL$_m$	
	0.86		Safe	
	16.0	30 days	TL$_m$	Lemke and Mount, 1963.
	5.6	90 days	Gill damage	Cairns and Scheier, 1963.
	17.0	96 hours	TL$_m$	
Fathead minnows	2.3		Reduced spawning	Pickering, 1966.
	13.0	96 hours	TL$_m$	Henderson, et al., 1959.
	11.3	96 hours	TL$_m$	Thatcher, 1966.
Fathead minnow fry	3.1	7 days	TL$_m$	Pickering, 1966.
Pumpkinseed sunfish	9.8	3 months	Gill damage	Cairns and Scheier, 1964.
Salmon	5.6	3 days	Mortality	Holland, et al., 1960.
Yellow bullheads	1.0	10 days	Histopathology	Bardach, et al., 1965.
Emerald shiner	7.4	96 hours	TL$_m$	Thatcher, 1966.
Bluntnose minnow	7.7	96 hours	TL$_m$	Thatcher, 1966.
Stoneroller	8.9	96 hours	TL$_m$	Thatcher, 1966.
Silver jaw	9.2	96 hours	TL$_m$	Thatcher, 1966.
Rosefin	9.5	96 hours	TL$_m$	Thatcher, 1966.
Common shiner	17.0	96 hours	TL$_m$	Thatcher, 1966.
Carp	18.0	96 hours	TL$_m$	Thatcher, 1966.
Black bullhead	22.0	96 hours	TL$_m$	Thatcher, 1966.
"Fish"	6.5		Min. lethality	Leclerc and Devlaminck, 1952.
Trout sperm	10.0		Damage	Mann and Schmid, 1961.
Daphnia	5.0	96 hours	TL$_m$	Sierp and Thiele, 1954.
	20.0	24 hours	TL$_m$	Godzch, 1961.
	7.5	96 hours	TL$_m$	Godzch, 1961.
Lirceus fontinalis	10.0	14 days	6.7 percent survival (hard water).	Surber and Thatcher, 1963.
Crangonyx setodactylus[1]	10.0	14 days	0 percent survival (hard water).	Surber and Thatcher, 1963.
Stenonema ares	8.0	10 days	20–33 percent survival.	Surber and Thatcher, 1963.
Stenonema heterotarsale	16.0	10 days	0 percent survival	Surber and Thatcher, 1963.
	8.0	10 days	40 percent survival	Surber and Thatcher, 1963.
Isonychia bicolor	16.0	10 days	0 percent survival	Surber and Thatcher, 1963.
	8.0	9 days	0 percent survival	Surber and Thatcher, 1963.
Hydropsychidae (mostly cheumatopsyche).	16.0	12 days	37–43 percent survival.	Surber and Thatcher, 1963.
Orconectes rusticus	32.0	12 days	20 percent survival	Surber and Thatcher, 1963.
	16.0	9 days	100 percent survival	Surber and Thatcher, 1963.
Goniobasis livescens	32.0	9 days	0 percent survival	Surber and Thatcher, 1963.
	16.0	12 days	40–80 percent survival.	Surber and Thatcher, 1963.
Snail	32.0	12 days	0 percent survival	Surber and Thatcher, 1963.
	18.0	96 hours	TL$_m$	Cairns and Scheier, 1964.
	24.0	96 hours	TL$_m$	Cairns and Scheier, 1964.
Chlorella	3.6		Slight growth reduction.	Maloney, 1966.
Nitzchia linearis	5.8		50 percent reduction in growth in soft water.	Cairns, et al., 1964.
Navicula seminulum	23.0		50 percent reduction in growth in soft water.	Cairns, et al., 1964.

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[1] Misidentified originally as Synurella.

toxic in soft water than in hard water (Patrick, unpublished data). For *Nitzchia linearis* a 50-percent reduction in growth of the population in soft water (44 mg/l Ca-Mg as $CaCO_3$) occurred as follows: 0.288 mg/l (CN) at 72 F, 0.295 mg/l at 82 F, and 0.277 mg/l at 86 F. For *Navicula seminulum* var. hustedtii, the concentrations that reduced growth of the population 50 percent in hard water (170 mg/l Ca-Mg as $CaCO_3$) were as follows: 0.356 mg/l at 72 F, 0.491 mg/l at 82 F, and 0.424 mg/l at 86 F.

Recommendation: Permissible concentrations of cyanide should be determined by the flow-through bioassay method described in the bioassay section. These tests should be conducted with DO, temperature, and pH at recommended levels for the factors under which the cyanide (HCN) is most toxic or under local water conditions at which it is the most toxic.

Ammonia: The toxicity of ammonia has been studied by several investigators but because of inadequate reporting and unsatisfactory experimental control, much of the work is not usable. Doudoroff and Katz (1950), Wuhrmann, et al. (1947), and Wuhrmann and Woker (1948) give a complete account of the pH effect on ammonia toxicity and demonstrate that toxicity is dependent primarily on undissociated NH_4OH and nonionic ammonia. They found no obvious relationship between time until loss of equilibrium and total ammonium content. They also demonstrated a striking synergy between ammonia and cyanide. McKee and Wolf (1963) state that toxicity is increased markedly by reduced dissolved oxygen. Field studies by Ellis (1940) and other observations lead to the conclusion that at pH levels of 8.0 and above total ammonia expressed as N should not exceed 1.5 mg/l. It has been found that 2.5 mg/l total ammonia expressed as N is acutely toxic.

Recommendation: Permissible concentrations of ammonia should be determined by the flow-through bioassay with the pH of the test solution maintained at 8.5, DO concentrations between 4 and 5 mg/l, and temperatures near the upper allowable levels.

Others: Especially significant sources of wastes that must be considered individually are derived from tar, gas, and coke-producing plants, pulp and paper mills, petroleum refining and petrochemical plants, waterfront boating activities, and special-purpose laboratories. These problems are discussed in the toxicity portion of the section on water quality requirements for marine organisms.

marine and estuarine organisms

ESTUARIES are recognized as being of critical importance in man's harvest of economically useful living marine resources. It is in these areas that the maximum conversion of solar energy into aquatic plant life takes place and they are justly identified as "nurseries" since so many animals utilize them for feeding their early life stages. Some species, such as the oyster, spend their entire life span in the estuary, while the shrimp and menhaden reside there only as juveniles. The salmon and a few others use the estuary primarily as a pathway. In sum, however, more than half of the over 4.5 billion pounds of fishery products harvested by U.S. fisherman annually is derived from animals dependent for their existence on clean estuarine waters during some part or all of their life cycle.

Pollution of estuarine and coastal waters is difficult to assess because of the special qualities of this environment. Technically, any foreign substance or environmental condition that interferes with a desired use may be considered a pollutant, but we are concerned with those substances present at high enough concentrations or environmental changes great enough to cause deleterious effect. Many naturally occurring substances in salt water become toxic when their concentrations are increased artificially or by natural processes.

The problem in establishing criteria in estuaries arises from the fluctuating nature of the water quality, both daily and seasonally, and geographically within the estuary. Changes in salinity, pH, turbidity, and temperature may alter greatly the critical toxic concentration of a pollutant. Most chlorinated hydrocarbon pesticides, for example, are significantly more acutely toxic at summer rather than winter water temperatures and at least one of the common detergents becomes decidedly more toxic to fish as salinity levels increase.

The most obvious effect of tidal action in the estuary is to change water depth. This indirectly changes current patterns, water temperature, and the density of motile animal populations. Depending on the geography of the estuary and the amount of fresh water drainage into it, salinity patterns may vary from relatively uniform conditions throughout a tidal cycle to situations in which the water is clearly stratified with a layer of relatively fresh water overlying the bottom salt water, or to situations in which the major portion of the water mass changes from fresh to salt and back to fresh again.

In shallow, broad estuaries, wind may be the dominant factor in causing water movements which change salinity and temperature patterns. The volume of fresh water discharged into an estuary may be a major factor in establishing coastal currents that transport pollution loads from one region to another.

We are dealing, then, with an environment in which the characteristics of the receiving water are usually fluctuating, frequently unexpectedly. As a result, its ability to dilute and disperse a burden of toxicants is unpredictable without detailed local investigations.

Pollution in the estuary may be derived from contamination hundreds of miles upstream in the river basin or it may be of purely local origin. Silt plays a major role in the transport of toxicants, especially pesticides, down to the estuary. Agricultural chemicals are adsorbed on silt particles. Under poor farming practices, as much as 11 tons of silt per acre per year may be washed by surface water into a drainage basin. Surface mining and deforestation further accelerate the process of erosion and permit the transport of terrestrial chemical deposits to the marine environment.

Atmospheric drift is also an important factor in the transport of pollutants to the aquatic environment (Cohen and Pinkerton, 1966). Much of the tonnage of aerially applied pesticides fails to reach the designated spray areas and the presence of 5 μg/l of DDT in presumably untreated Alaskan rivers indicates the magnitude of this facet of the pollution problem. The continuous presence of 5 μg/l of DDT in the marine environment would decrease the growth of oyster populations by nearly 50 percent.

Toxic pollutants may be passed directly into the marine environment as contaminants of industrial and domestic waste effluents or they may be intentionally placed there as in the control of various noxious insects by spraying marsh and littoral habitats with synthetic pesticides. Experimentally, some synthetic insecticides have been applied directly to estuarine bottoms in efforts to control oyster pests.

Finally, there are naturally occurring substances such as lignins and phosphate compounds which in times of flood may be carried to the estuary in sufficient quantity to constitute a pollution hazard.

Salinity

The spatial and temporal distribution of salinity profoundly affects the activities of many estuarine species in tidal tributaries (Andrews, 1964; Emery and Stevenson, 1957; Hargis, 1965 and 1966; Pearse and Gunter, 1957; Pritchard, 1953). Some bottom organisms, e.g., *Crassostrea virginica*, are able to survive lower salinities than can their predators and disease-causing organisms. Hence, in some tidal tributaries, oysters thrive in regions where they are sheltered from these pests by low salinity. Natural alterations in salinity distribution have been reportedly followed by increased mortality of oysters. It is clear that care must be exercised in the approval of engineering projects or industrial processes that will alter salinity regimes in tidal tributaries and lagoons and in their associated wetlands.

Salinity patterns can be caused to vary from "normal" by alterations in character of freshwater inflow and basin geometry. These are the same factors that produce changes in circulation. In fact, salinity alterations are precursors to changes in density currents.

Recommendation: For the protection of estuarine organisms, no changes in channels, in the basin geometry of the area, or in fresh water inflow should be made that would cause permanent changes in isohaline patterns of more than ±10 percent of the natural variation.

Currents

Despite their large volumes, tidal waters, especially those in tributaries of the seas, have special circulatory characteristics that may affect their ability to assimilate wastes. For example, tidal action slows the already slowed (due to lowered slope and resulting reduced speed of gravity-induced flow) seaward movement of water in tidal rivers and streams. This alternate up and down stream movement of the water in the freshwater portion of the tidal tributary is confounding enough in itself (Ketchum, 1950 and 1951; Stommel, 1953a, b) but in the estuarine reach, the area where sea salts are noticeable, further complexities often occur (Bowden, 1963; Hargis, 1965; Redfield, 1951). In horizontally and vertically stratified mixing estuaries, there are two streams. The upper stream, fresher and lighter, has a net-flow downstream while the lower stream, saltier and heavier, flows inward or upstream. Since these surface currents and bottom counter-currents often extend far to sea off the mouths of large tidal tributary or estuarine systems, as well as far upstream, significant upstream transport of materials in solution or suspension in the counter-current can occur. These circulatory features are important in the life cycles of many estuarine species. For example, oyster and barnacle setting is related to tidal and nontidal currents (Barlow, 1955; Bousfield, 1955; Emery and Stevenson, 1957; Hargis, 1966; Ketchum, 1954; Pritchard, 1953). Large disturbances of current patterns can disrupt the life cycles of estuarine organisms. Hence, projects that alter current patterns should be carefully evaluated and controlled.

It is possible to alter circulatory patterns in tidal tributaries by (1) changing the quantity, timing, and location of fresh water inflow, (2) changing the geometry of the basin. The former can be accomplished by construction and operation of reservoirs above or below the fall line (defined as the uppermost limit of ocean's tidal activity). The latter can be accomplished by shoreline or bottom modification; e.g., drainage, bulkheading and filling, channel dredging, and subaqueous spoil disposal or mining. Oyster harvesting practices have been known to produce marked changes in bottom geometry (Hargis, 1966).

Recommendation: In view of the requirements of estuarine organisms and the nature of marine waters, no changes in basin geometry or fresh water inflow should be made in tidal tributaries which will alter current patterns in such a way as to cause adverse effects.

pH

Despite the great emphasis given to the importance of pH in the literature, little is known of its direct physiological effects on marine organisms. Its indirect effects, however, are extremely significant. Even a slight change in pH indicates that the buffering system inherent in sea water has been altered radically and that either a potential or actual carbon dioxide imbalance exists. This imbalance can be deleterious or disastrous to marine life. A second indirect effect is that pH can influence the toxicity of other materials. Cyanide and ammonia, discussed under "Toxicity," are outstanding examples of this kind of action.

Recommendation: Materials that extend normal ranges of pH at any location by more than ±0.1 pH unit should not be introduced into salt water portions of tidal tributaries or coastal waters. At no time should the introduction of foreign materials cause the pH to be less than 6.7 or greater than 8.5.

Temperature

Temperature requirements of marine and estuarine organisms in the biota of a given region may vary widely. Therefore, if we are to maintain temperature favorable to the biota, all important species, including the most sensitive, must be protected. It has been found that organisms in the intertidal zone vary considerably in their ability to withstand high temperatures. Those in the uppermost areas of the tidal zone generally can withstand higher temperatures than those in the lower portions of the tidal zone and these in turn generally can withstand higher temperatures than the same species of animals living in the subtidal zones. In addition, when considering the coastline as a whole, we must recognize that there are various races within a given species which may vary considerably in their environmental requirements, or in their ability to withstand extreme conditions.

In our marine waters, there is a great mixture of species. Species typical of higher latitudes are found with species that are more abundant farther south. Tropical or subtropical species generally will spawn in the summer months. Species from the higher latitudes require low water temperature for spawning and the development of the young. Thus, they usually spawn in the winter months and temperatures at that time are critical. Any warming of the water during the cold weather or winter period could be disastrous from the standpoint of the elimination of the more northerly species. In some instances, a rise in winter temperatures of only 2 or 3 F might be sufficient to prevent spawning and thus eliminate these species from the biota.

In the northern portions of the country there is generally a great range in natural temperatures. In southern areas, as we approach the tropics, we find smaller overall temperature ranges. In the tropics or subtropics, optimum temperatures for many forms are only a few degrees lower than maximum lethal temperatures. Great care should be exercised, therefore, to prevent harmful increases in maximum summer temperatures in tropical areas.

In general, temperatures in the marine waters do not change as rapidly nor do they have the overall range from extreme to extreme as they do in fresh waters. Marine and estuarine fishes, therefore, are less tolerant of temperature variation. They can accommodate somewhat, but overall temperature range and rate of change are even more important here than they are in fresh waters. It has been observed that when surface water temperatures over the Georges Bank increased from 46 to 68 F, the larval fish died at 65 F. It has been found that species in subtropical and tropical environments are living at temperatures that are only a few degrees less than their lethal temperatures. In the most northern forms, extensive variations in seasonal temperatures are a necessity for orderly development and growth. Spawning and development frequently occur at lower temperatures and the sexual products ripen on rising temperatures after a period of low temperatures. Temperatures above or below the optimum range may delay or speed up development. They may inhibit swimming ability and the effectiveness of food utilization may be decreased with increasing temperatures in the upper viable range. Fishes and other forms are also more susceptible to parasites and diseases at temperatures outside of their optimum range. In regard to rapid changes in temperature, it has been found that a drop in temperature from 58 to 43 F kills sardines. Tolerable temperature minima vary with the population and its past temperature history. Kills have occurred off the Texas coast at 40 F whereas kills of the same species have occurred off Bermuda at a drop to 59 F. Many kills have occurred in nature due to unusually low temperatures. Kills also occur due to natural high temperatures. Yellowtail flounder and whiting larvae died when they drifted from an area of 44 F to one of 64 F. It has been reported that 61 F is best for the developing of mackerel, but 70 F is too high. These are merely illustrations of what might happen to species occurring in inshore waters.

It is apparent from the foregoing that data are very sparse on temperature requirements of marine and estuarine species. It is very difficult, therefore, to attempt to suggest temperature requirements for marine and estuarine forms. The difficulty is compounded by the great extent of the Nation's shorelines, the differing natural temperature variations from north to south, and the geographic overlapping of species native to different latitudes. Consideration must be given to maximum allowable temperatures for both the summer period and the winter period.

In attempting to establish permissible levels of temperature increase in receiving waters due to heated waste discharges, precaution must be taken to prevent—

(a) excessive incremental increases above background values even though such incremental increases lie below maximum limits, and

(b) exceeding maximum natural background limits.

Such precautions are necessary to prevent gradual net increases in background temperatures due to the continuously increasing volumes of heated wastes being discharged into receiving waters.

The discharge of heated wastes into estuaries and other tidal tributaries must be managed so that no barrier to the movement or migration of fish and other aquatic life is created.

Recommendation: In view of the requirements for the well-being and production of marine organisms, it is concluded that the discharge of any heated waste into any coastal or estuarine waters should be closely managed. Monthly means of the maximum daily temperatures recorded at the site in question and before the addition of any heat of artificial origin should not be raised by more than 4 F during the fall, winter, and spring (September through May), or by more than 1.5 F during the summer (June through August). North of Long Island and in the waters of the Pacific Northwest (north of California), summer limits apply July through September, and fall, winter, and spring limits apply October through June. The rate of temperature change should not exceed 1 F per hour except when due to natural phenomena.

Suggested temperatures are to prevail outside of established mixing zones as discussed in the section on zones of passage.

Dissolved oxygen

Dissolved oxygen requirements of marine organisms are not as well known as those for freshwater forms. Studies have been made indicating that minimum dissolved oxygen concentrations of 0.75 to 2.5 are required for test species to resist death for 24 hours. Most marine species died when the dissolved oxygen dropped below 1.25 mg/l for a few hours. Reduced swimming speed and changes in blood and serum constituents occurred at dissolved oxygen levels of 2.5 to 3 mg/l. It was found that DO levels between 5.3 and 8 mg/l were satisfactory for survival and growth. Levels above 17 mg/l, however, produced adverse effects. Large fluctuations in dissolved oxygen from 3 to 8 mg/l, diurnal or otherwise, produced significantly more physiological stress in fishes than fluctuations from 3 to 6 mg/l. In tests made to date, it has been found that 5 to 8 mg/l of DO is apparently sufficient for all species of fish for good growth and general well being. It is generally recognized that in deeper waters DO values are often considerably less than 5.0 mg/l In estuaries where there is a reduction in salinity, levels may drop to as low as 4 mg/l at infrequent intervals and for limited periods of time. It is probable that many marine animals can live for long periods of time at much lower levels of DO. Experimental studies with freshwater organisms have demonstrated, however, that low concentrations of DO at which adult fishes can live almost indefinitely, can inhibit feeding and growth. In determining DO requirements, it is essential to consider growth, reproduction, and other necessary life activities.

Recommendation: For the protection of marine resources, it is essential that oxygen levels shall be sufficient for survival, growth, reproduction, the general well-being, and the production of a suitable crop. To attain this objective, it is recommended that dissolved oxygen concentrations in coastal waters, estuaries, and tidal tributaries of the Nation, including Puerto Rico, Alaska and Hawaii, should be as follows:

(1) Surface dissolved oxygen concentrations in coastal waters shall not be less than 5.0 mg/l, except when natural phenomena cause this value to be depressed.

(2) Dissolved oxygen concentrations in estuaries and tidal tributaries shall not be less than 4.0 mg/l at any time or place except in dystrophic waters or where natural conditions cause this value to be depressed.

The committee would like to stress the fact that, due to a lack of fundamental information on the DO requirements of marine and estuarine organisms, these requirements are tentative and should be changed when additional data indicate that they are inadequate.

Crude oil and petroleum products

The discharge of crude oil and petroleum products into estuarine and coastal waters presents special problems in water pollution abatement. Oils from different sources have highly diverse properties and chemistry. Oils are relatively insoluble in sea and brackish waters and surface action spreads the oil in thin surface films of variable thickness, depending on the amount of oil present. Oil, when adsorbed on clay and other particles suspended in the water, forms large, heavy aggregates that sink to the bottom. Additional complications arise from the formation of emulsions in water, leaching of water soluble fractions, and coating and tainting of sedentary animals, rocks, and tidal flats.

Principal sources of oil pollution are numerous. Listed in order of their destructiveness to ecosystems, they are:

(1) Sudden and uncontrolled discharge from wells towards the end of drilling operation.

(2) Escape from wrecked and submerged oil tankers.

(3) Spillage of oil during loading and unloading operations, leaky barges, and accidents during transport.

(4) Discharge of oil-contaminated ballast and bilge water into coastal areas and on the high seas.

(5) Cleaning and flushing of oil tanks at sea. On the average, a ship's content of such wastes is estimated to contain 2 to 3 percent oil in 1,000 to 2,000 tons of waste.

(6) Spillage from various shore installations, refineries, railroads, city dumps, garages, and various industrial plants.

Spillage From Wrecked Oil Tankers

Even though wrecks of oil tankers along the Atlantic coast and subsequent spillage of oil into the sea have been reported several times, no thorough examination has been made of the effect of oil pollution on local marine life, except for frequent references to the destruction of waterfowl. One of these disasters attracted the general attention of the public and members of the Audubon Society of New England. One night in 1952, two tankers, the *Fort Mercer* and the *Pendleton,* went aground on the shoal of Monomoy Point, Cape Cod. Large amounts of oil spilled from the broken vessels, spread long distances along the shore, and were responsible for high mortality of ducks (scoters and eiders). Many thousands of oil-smeared dying birds were seen along the coast. Attempts to save some of the birds by removing the oil with various solvents failed. No published records are found on the effect of this massive spillage on aquatic life. According to the records of the Massachusetts Audubon Society, serious oil spreads threatening fish and bird life have occurred at least six times since 1923 along the beaches of Cape Cod. The latest occurrence was on Sunday, April 16, 1967. Heavy films of crude oil appeared along the coast from Chatham to Provincetown, Mass. and spread to Cape Cod Bay, Nantucket Island, and Boston. The shores of the National Seashore Park were seriously affected and hundreds of ducks and brant were found dead or dying.

The massive spillage of oil may constitute a disaster of a national and even international magnitude as has been dramatically demonstrated by the wreck in March 1967 of the super tanker *Torrey Canyon* carrying 118,000 tons of crude oil. About one-half of the load gradually spilled near Seven Stones Reef, off the southern coast of England, where the tanker was stranded. By the middle of April, patches of crude oil began to appear on the French coast in Brittany, threatening the productive oyster farms in the inlets and estuaries. It is obvious that a disaster of such magnitude is beyond the scope of an ordinary pollution problem in coastal waters. The probability of a recurrence of heavy oil spillage is, however, very real because of the present trend in the methods of transporting oil in very large and apparently vulnerable tankers. It has been reported that Japan operates a tanker, *Idemitsu Maru,* of 205,000 tons holding capacity. A super tanker of over 300,000 tons capacity is under consideration and a design of a 500,000-ton tanker appeared in the press.

Effect of Oil Spillage on Aquatic Life of a Small Marine Cove

W. J. North, et al. (1965) made a valuable study of the effect of massive spillage of crude oil into a small cove in lower California Bay. Prior to the spillage, the investigators were engaged in a study of bottom fauna and flora of the cove and were in possession of background information which made it possible for them to record the changes that took place after the water of the cove was contaminated by the 59,000 barrels of oil that escaped from the wreck of the tanker *Tampico* on March 29, 1957. Among the many dead and dying species observed a few weeks after the disaster, the most frequently found were abalones (*Haliotis fulgens, H. rufescens,* and especially *H. cracherodii*), lobsters (*Panulirus interruptus*), pismo clams (*Tivela stultorum*), mussels (*Mytilus sp.*), sea urchins (*Strongylocentrotus franciscanus, S. purpuratus*), and sea stars (*Pisaster giganteus, P. ochraceus*). A slight improvement of the bottom fauna was noticeable a few months after the disaster, but extensive recovery became apparent only 2 years later. Four years after the accident, the populations of abalones and sea urchins still were reduced greatly and seven species of animals previously recorded in the cove had not been found at all.

Combined Effect of Oil and Sewage Pollution

The oil and sewage pollution effects on aquatic organisms of the Novorossiyak Bay (Black Sea, U.S.S.R.) was recently studied by Kalugina, et al. (1967). For a number of years, this bay has been receiving a mixed daily discharge of 15,000 to 30,000 cubic meters of petroleum refinery wastes and domestic sewage. There is marked decrease of various valuable species of mollusks (*Spisula subtruncata, Tapes rugatus, Pecten ponticus*) and complete destruction of oyster beds (*Ostrea taurica*) due to the combined effect of pollution and depradations by a carnivorous gastropod (*Rapana*). Samples were collected 1 to 25 meters from the outfall for bioassay. Copepods (*Acartia clausi*) placed in samples taken 25 meters from the outfall were killed in 24 hours. Larvae of decapods and gastropods in samples taken 10 to 25 meters out perished in 3 to 4 days. *Calanus* was killed in 5 days in samples taken 1 meter out, but survived the 10-day test in the samples taken 5, 10, and 25 meters from the outfall. There also was a noticeable change in the distribution and species composition of benthic algae.

Color of Oil Film on the Surface of Water

The color of the oil film on the water surface is indicative of the thickness of the slick and may be used as an indicator of the volume of oil spilled.

According to data published by the American Petroleum Institute (1949), the first trace of color that may be observed as a surface film on the sea is formed by 100 gallons of oil spread over 1 square mile. Films of much darker colors may indicate 1,332 gallons of oil per square mile. Experiments conducted by the Committee on the Prevention of Pollution of the Seas (1953) showed that 15 tons of oil covered an area of 8 square miles. In 8 days, it had drifted about 20 miles from the point of discharge. The same committee (1953) indicated another source of oil pollution that should not be neglected. It has been found that unburned fuel oil escaping through the funnels of oil-burning ships may comprise 1 to 2 percent of the total oil consumed and it may be deposited on the sea surface. British investigators attributed the disappearance of eel grass (*Zostera*) to minute quantities of oil. Oil weakens the plant and makes it susceptible to attacks of a parasitic protozoan (*Labyrinthula*). Observations made several years ago at Woods Hole showed that young *Zostera* that began to reappear in local bays after several years of absence were already infected by this microorganism even though they appeared to be healthy.

Adsorption of Oil by Sand, Clay, Silt, and Other Suspended Particles

Oil of surface films is easily adsorbed on clay particles and other suspended materials, forming large and relatively heavy aggregates that sink to the bottom. The surface of the water may appear free from pollution, until the sediment is stirred by wave action and the released oil floats up again.

During World War II, a product known as "carbonized sand" was manufactured for the U.S. Navy and used for the primary purpose of rapidly removing oil spilled or leaked from ships. Carbonized sand was used principally as a rapid method to prevent and stop fires. Sand and oil aggregates, being much heavier than sea water, sank very rapidly and remained on the bottom. Experimental work has shown that the toxic effect of oils is not diminished by this method (Chipman and Galtsoff, 1949). Since the end of World War II, a number of preparations to be used as solvents, emulsifiers, and dispersing agents of oil slicks in harbor waters appeared in New Zealand, Western Europe, and the United States. These preparations are being offered under various trade names and their chemical composition is not always stated. It is often claimed that such compounds remove oil slicks more efficiently than mopping with straw or coarse canvas fabric (skrim), a method extensively used in Auckland Harbor (Chitty, 1948). It is, however, generally recognized that various detergents and emulsifiers are toxic to aquatic life and therefore compound the danger of oil pollution. Mechanical means such as preventing the spread of a slick by surrounding it with floating barriers (plastic booms), spreading sawdust and removing an oil aggregate by scooping or raking, and erecting grass or straw barriers along the beaches are probably more effective at present than the chemical methods of dispersing or dissolving oil. Even anchoring oil by combining it with relatively heavy carbonized sand seems to be preferable to chemical methods.

Toxicity of Crude Oil and Petroleum Products

Oil may injure aquatic life by direct contact with the organism, by poisoning with various water soluble substances that may be leached from oil, or by emulsions of oil which may smear the gills or be swallowed with water and food. A heavy oil film on the water surface may interfere with the exchange of gases and respiration.

A number of observations have been recorded of the concentrations of oil in sea water which are deleterious to various species. Experimental data, however, are scarce and consequently the toxicology of oil to marine organisms is not well understood.

Nelson (1925) observed marine mollusks (*Mya arenaria*) being destroyed by oil on tidal flats of Staten Island, N.Y. The Pacific coast sea urchin, *Strongylocentrotus purpuratus*, dies in about 1 hour in a 0.1 percent emulsion of diesel oil. After 20 to 40 minutes in this concentration the animals fail to cling to the bottom and may be washed away (North, et al., 1964).

Crude oil absorbed by carbonized sand does not lose its toxicity. This has been shown by laboratory experiments conducted at Woods Hole (Chipman and Galtsoff, 1949). The amount of oil used was limited to the quantity held in the sand, hence no free oil was present in the water. The oil-sand aggregates were placed in containers filled with sea water but never came into contact with the test animals. Four species were bioassayed: the very hardy toadfish (*Opsanus tau*) in the yolk sac stage, the moderately tolerant barnacle (*Balanus balanoides*), and oyster (*Crassostrea virginica*), and the extremely sensitive hydrozoan, (*Tubularia crocea*).

The survival of toadfish embryos was indirectly proportional to the concentration of oil in water.

In a concentration of 0.5 percent, the embryos survived for 13 days (end of test); in 1.25 percent, 8½ days; in 2.5 percent, 6 days; and in 5 percent, 4½ days. Barnacles suffered 80 to 90-percent mortality within 70 hours in 2.0-percent mixtures of oil in sea water. They became inactive in 23 hours in concentrations of 2 percent and above. *Tubularia* suffered 90 to 100-percent mortality within 24 hours after being placed in water containing a 1:200 oil-carbonized sand aggregate. Water extracts of crude oil were lethal within 24 hours at concentrations of 500 mg/l and greater.

Experiments with oysters consisted primarily of determining the effect of oil adsorbed on carbonized sand on the number of hours the oysters remain open and feeding and on the rate of water transport, across the gills. A paste-like aggregate of oil in carbonized sand (50 ml crude oil to 127 g sand) was prepared, wiped clean of excess oil, and placed in the mixing chamber. Sea water was delivered through this chamber to the recording apparatus at a rate slightly in excess of the rate of water transport by oyster gills (Galtsoff, 1964; Chipman and Galtsoff, 1949). There was a noticeable decrease in the number of hours the test oysters remained open and in the daily water transport rate through the gills. The time open was reduced from 95 to 100 percent during the first 4 days of testing to only 19.8 percent on the 14th day. The total amount of water transported per day, and presumably used for feeding and respiration, was reduced from 207 to 310 liters during the first 6 days to only 2.9 to 1 liter per day during the period between the eighth and 14th day of continuous testing. These tests indicate that oil incorporated into the sediments near oyster beds continues to leach water-soluble substances which depress the normal functions of the mollusk.

Critical observations are lacking on the effect of oil on pelagic larvae of marine invertebrates, but there is good reason to assume that crude oil and petroleum products are highly toxic to free-swimming larvae of oysters. Speer (1928) considers that they are killed by contact with surface oil film. Laboratory experience of Galtsoff (unpublished records) shows that oyster larvae from 5 to 6 days old were killed when minor quantities of fuel oil were spilled by ships in the Woods Hole harbor and the contaminated water penetrated into the laboratory sea water supply.

The tests described above leave no doubt that water-soluble substances are leached from oil spilled into water and adversely affect marine life. It is reasonable to assume that the water soluble materials of oil may contain various hydrocarbons, phenols, sulfides, and other substances toxic to aquatic life. The water-soluble fraction leached from crude oil is easily oxidized by aeration and loses its toxicity (Chipman and Galtsoff, 1949).

Carcinogenic Substances From Oil-Polluted Waters

Presence of hydrocarbons similar to benzopyrene in oil-polluted coastal waters and sediments of France in the Mediterranean was reported by Mallet (1965) and Mallet and Sardou (1965). The effluents from the industrial establishments on the shores at Villefranche Bay comprise tar substances, which contain benzopyrenes, benzo-8, 9-fluoranthene, dibenzanthracenes, chrysene, 10-methyl anthracene, and nitrogenous derivatives such as dimethylbenzacridine. These substances are carried out into the bay water and settle on the bottom. The pollution is augmented by incompletely burned oils discharged by turbine ships. The content of benzopyrene in bottom sediments ranges from 500 micrograms in 100 g sample collected at the depth of 8 to 13 cm to 1.6 micrograms at 200 cm. Similar contamination is of importance in the Gulf of Fos, Etang de Berne, and in the delta of the Rhone River.

Carcinogenic hydrocarbons were found to be stored in plankton of the bay of Villefranche, in concentrations varying from 2.5 to 40 micrograms per 100 g. Fixation of benzopyrenes was found also in the bodies of holothurians (Lalou, 1965) in a bay near Antibes. The reported concentration in the visceral mass of holothurian was slightly higher than that in the bottom sediment.

Observations on storage of carcinogenic compounds found in oil-polluted water are biologically significant. The important question of biological magnification as these compounds are ingested by plankton feeders remains unanswered and needs to be investigated.

Sampling of Oil-Polluted Sea Water

The question of the minimal concentration of oil and petroleum products consistent with uninhibited growth and reproduction of aquatic species is more difficult to answer than it is in the case of other contaminants. As has been shown above, oil is found in water in four distinct phases: (1) surface oil film, (2) emulsion in sea water, (3) extract of water soluble substances, and (4) semi-solid aggregate of oil and sediment covering the bottom. Obviously, no single sample could include all four phases and the method of sampling should vary accordingly. Collection of samples of a heavy oil slick near the origin of spillage presents no particular difficulty because an adequate quantity may be scooped easily and placed in a proper container. Serious difficulty arises, however, in case of an irridescent film of oil approaching the thickness of a monomolecular layer. Garrett (1964), made a special study of slick-forming materials naturally occurring on sea surfaces and demonstrated their highly complex composition. The collection of very thin layers of surface water was made by means of a specially constructed plastic screen. The entrapped compounds were washed off into a large container (Garrett, 1962). He found surface-acting substances in all areas where the sea surface was altered by monomolecular films and concluded that "a chemical potential exists whereby such surface alterations can occur when conditions are suitable for the adsorption and compression of the surface-active molecules at the air/water boundary." The oil film at the air/water boundary may be composed of several interacting organic compounds. This complexity must be kept in mind in studies of oil pollution in sea water.

If a relatively thick layer of contaminated water is needed, the sample may be scooped or sucked from an area of sea surface enclosed by a floating frame. Interference due to wave ripples is minimized in this way.

For analysis of an oil emulsion in sea water, a sample of a desired volume may be collected by pump or by any type of self-closing water bottle lowered within the surf area.

For obtaining water soluble substances leached from oil sludge, sampling should be made by pumping or by using a water sampler lowered as close as possible to the oil-covered bottom.

Samples of oil adsorbed on sediments can be obtained by using bottom samplers designed to take quantitative samples.

Contamination of beaches by floating tar ballast and cleaning water discharged by ships sailing along our coast is of such common occurrence that at present it is almost impossible to find a public beach free from this nuisance. Cakes of solidified oil tar can be picked by hand from the tidal zone of any beach along the Atlantic and Gulf coasts.

Recommendation: Until more information on the chemistry and toxicology of oil in sea water becomes available, the following requirements are recommended for the protection of marine life. No oil or petroleum products should be discharged into estuarine or coastal waters in quantities that (1) can be detected as a visible film or sheen, or by odor, (2) cause tainting of fish and/or edible invertebrates, (3) form an oil-sludge deposit on the shores or bottom of the receiving body of water, or (4) become effective toxicants according to the criteria recommended in the "Toxicity" section.

Turbidity and color

Turbidity, color, and transparency are closely interrelated phenomena in water. They must be observed simultaneously because transparency is a function of turbidity, water color, and spectral quality of transmitted light. For practical purposes, however, it is more convenient to discuss them separately.

Turbidity

By observing the turbidity of sea water it is possible to determine the depth of the euphotic zone; i.e., the depth in which organic carbon is produced. Various particles suspended in water reduce the intensity of light by absorption and scattering. In the sea, the maximum depth of growth of attached plants varies. It is 160 m in the Mediterranean, 30 m in Puget Sound, and 10 m off Cape Cod. In general, benthic plants will not grow at a depth at which the light intensity is less than 0.3 percent of its surface value (Clarke, 1954). In any environment, the rate of photosynthesis decreases with the attenuation of light but the respiration rate remains approximately the same. Because the role of phytoplankton in organic production is far more important quantitatively than that of benthic plants, an increase in the turbidity of water diminishes primary productivity of the ocean biomass as indicated by the rate of growth of various planktonic algae.

For each species of plant, a level of light intensity may be reached at which the rate of photosynthesis becomes equal to the rate of respiration. This level is designated as compensation intensity and the depth at which this value is found is called the compensation depth. For marine phytoplankton, it has been determined that compensation intensity is about 100 ft-candles, or 1 percent of the value of full sunlight (Clarke, 1954). In natural waters, the compensation depth varies; e.g., in the Gulf of Maine it was found to be 30 m while at Woods Hole only 7 m.

In many coastal waters, the principal cause of turbidity is the discharge of silt carried out by the principal rivers. Secchi disc readings show that the transparency of water at the mouths of large rivers during flood stage may be reduced to a few centimeters. At normal river stages, the disc may be visible at several meters below the surface. Observations from an airplane are useful in recording the distribution of brackish, silt-laden waters along the coast. Silting of the estuaries and adjacent coastal water should be considered as a special case of pollution resulting from deforestation, overgrazing and faulty agricultural practices, road construction, and other land management abuses.

Mixed effluents from various industrial plants and domestic sewage increase the turbidity of receiving water. It is difficult to distinguish between the effect of the attenuation of light due to suspended particles and the direct effect of the particles in suspension on the growth and physiology of aquatic organisms. Natural silt taken from the bottom of the sea and kaolin affect the development of eggs and the growth of larvae of oysters and hard shell clams (*Mercenaria mercenaria*). In a suspension of 2 g of dry silt in a liter of sea water, only 39 percent of oyster larvae completed development. In 3 g per liter there was no development (Loosanoff, 1962). Growth of *Mercenaria* clams was retarded in the concentration of 1 to 2 g/l, but appeared to be normal at 0.75 g/l. Development was completely suppressed in the concentration of silt from 3 to 4 g/l (Davis, 1960). Silt concentration of 0.1 g/l caused a 57-percent decrease in the water transport of an adult oyster. In 4 g/l, the depression was 94 percent (Loosanoff, 1962). The turbidity used in these experiments probably is equivalent to 750 to 4,000 mg/l of turbidity standards, although direct comparison of figures cannot be made accurately.

The principal significance of turbidity observations in a study of pollution is the determination of the depth of the euphotic zone as a factor affecting primary productivity of the sea (Ryther, 1963). Determination of the coefficient "k" defined as the natural logarithm of the fraction of incident light penetrating to a given depth is of great importance in studies of organic production. In the temperate and northern parts of the ocean, values of "k" range between 0.10 to 0.20 and correspond to depths of 50 to 25 m. In more turbid coastal waters, the coefficient of extinction is as high as 1.0 and a compensation depth of 5 m is commonly encountered. These values may be used as a basis for comparing the characteristics of uncontaminated waters with those of highly turbid and polluted waters of coastal and inshore areas. A considerable part of the turbidity of these areas is attributable to nonliving particles.

It must remembered, also, that very high turbidity of sea water may be due entirely to blooms such as are known to occur in red tide areas (Galtsoff, 1949) or as a result of unbalanced overfertilization such as is induced by organic wastes from duck farms in Great South Bay, N.Y. Turbidity may be determined practically by use of a Secchi disc. Turbidity may be determined more accurately by using the techniques described in Standard Methods for the Examination of Water and Wastewater, 12th edition (1965). Any turbidity of less than 1 m (by Secchi disc) or in corresponding Jackson units should be regarded with suspicion and the nature of suspended material as well as the composition of plankton determined.

Color

The color of sea water, expressed as dominant wave length in millimicrons ($m\mu$) covers the range from violet (400 to 465 $m\mu$) to red-purple (530 to 700 $m\mu$). Spectrophotometric methods, as described in Standard Methods for the Examination of Water and Wastewater, 12th edition (1965), should be used if careful study is required, particularly for determining the exact color of water contaminated with industrial wastes.

Monitoring the color changes of sea water yields information on the extent of intrusion of fresh water into the sea, the intensity and extent of silting, the location and extent of plankton blooms, the extent and distribution of pollution from industrial waste effluents, and the presence and probable thickness of oil film.

In brackish waters, the blue hue of the open sea is replaced by a greenish or yellowish color. Silting areas are recognizable by brown or yellowish discoloration. Red-brownish color is typical of the red tide caused by *Gymnodinium* and other species of dinoflagellates. Some of these are toxic to fishes and benthic invertebrates (Galtsoff, 1948, 1949). Mass production of forms such as the blue-green alga *Trichodesmium* gives the surface of the sea an appearance of "green meadow" as described for the Azov Sea by Knipowich (Galtsoff, 1949). Swarming of *Phaeocystis poucheti*, *P. globosa*, and *Rhizosolenia* have been reported to extend over hundreds of square miles of the open sea causing a distinct brownish discoloration.

Systematic studies have not been made yet to determine the optical characteristics of discolored sea water. It is reasonable to expect that such an investigation would be valuable in explaining the cause of discoloration and, in certain instances, may indicate the presence and nature of pollution. Light components specific for the contaminant entering sea water may be detected by the use of a spectrophotometer or with the recording SPOT spectroradiometer recently developed by Alfred C. Konrad of the Massachusetts Institute of Technology. This type of instrument is being used at present at the Woods Hole Oceanographic Institution and is proving very useful. Spectroradiometer observations can be made either from an airplane or from shipboard.

Recommendation: No effluent which may cause changes in turbidity or color should be added to, or discharged into, inshore or coastal waters unless it has been shown that it will not be deleterious to aquatic biota.

Settleable and floating substances

Settleable solids entering coastal waters include various products of forest industries such as sawdust, bark chips, wood fibers, sewage solids, and many industrial wastes. The old practice of dumping sawdust into tidal rivers was discontinued long ago, but its effect is still visible in the rivers of Maine. For instance, an area of the bottom of the Damariscotta River was still covered with a loose layer of sawdust about 2 to 3 feet deep in 1940, although operation of the lumber mills responsible for this deposition had ceased more than 50 years previous. The Damariscotta kitchen-midden on the banks of the river contains a huge accumulation of river oyster shells and some artifacts left here by the Indians who lived there for several centuries of pre-Colonial times. The habitat was so completely changed by pollution that at present there is hardly any benthic organism found on this formerly productive bottom (Galtsoff and Chipman, unpublished report).

Decay-resisting organic matter from wood fibers and waterlogged bark and chips constitutes, in places, a serious handicap to aquatic life. Settleable materials from mining operations and gravel and sand washing make the bottom unsuitable for aquatic life in the affected areas of the receiving bodies of water. Silting may be so heavy that the sediment brought in may completely fill the bay. One can see this in the eastern branch of Matagorda Bay, Tex., an area that has been completely obliterated within the last 25 years by the Colorado River.

Dredging of bays and tidal rivers for improvement of navigation occasionally presents serious problems. Benthic communities in the area near dredging operations may be destroyed or damaged by spoil deposition, increase in water turbidity, release of toxic substances accumulated in the mud of the polluted areas, and by changing the pattern of currents in the dredged area.

Careful studies of the effects of dredging on oyster-producing bottoms of the Santee River, S.C., were made in 1936 by G. Robert Lunz, Jr. (unpublished report), for the U.S. Corps of Engineers. No deleterious effect on oyster-producing bottoms was found. An examination made by the Bureau of Fisheries Laboratory at Woods Hole of dredging operations to deepen and enlarge the Cape Cod Canal disclosed that several productive oyster beds near the site of dredging were covered by 2 to 3 feet of sand and silt. The oysters were destroyed, but the grounds soon were re-populated by hard-shell clams and the productivity of the area restored.

Disposal of the huge quantities of garbage accumulated by large cities presents a special and difficult problem. The old practice of barging this waste out to sea and dumping it is highly objectionable. Incineration seems to be the answer. This creates, however, the problem of proper incineration of large quantities of materials without increasing air pollution over the metropolis. The city of Boston disposes of large amounts of accumulated garbage and trash by incineration and by dumping the ashes into the sea at a distance from shore. State and Federal authorities are engaged presently in a study of the chemical composition of ash and its possible effect on aquatic life in the sea. Preliminary analysis of an incinerated sample made by Ronald Eisler (personal communication) of the National Marine Quality Laboratory of the Federal Water Pollution Control Administration shows that aluminum, iron, and calcium were most abundant, followed by zinc, sodium, potassium, and lead. Other metals comprising more than 1 percent of the fraction soluble in 6NHCl include barium, chromium, and magnesium. It is evident that ash from this waste contains a fairly large percentage of heavy metals which may be accumulating in the bodies of fish and shellfish. The effect of ash on the behavior of fish is now being studied, but the results are not yet available.

Examples of industrial effluents containing materials that precipitate in sea water are the waste from titanium paint plants or the soap portion of the effluents from Kraft pulp mills. This fraction of the black liquor is precipitated from solution by salt, carried by the current of the receiving river, and eventually deposited on the bottom (Galtsoff, et al., 1947). Waste from several plants extracting titanium dioxide from ilemenite (ferrous titanate) produces serious pollution in the lower Patapsco River area near Baltimore. Because of the restricted circulation of water in the upper Chesapeake Bay, the effect is quite pronounced. Ferric hydroxide flocculation in the Patapsco River has been found detrimental to plankton. Diatoms were destroyed by flocculation and removed from plankton by settling with the iron particles. Considerable amounts of iron accumulated on the bottom and iron precipitate was found coating the gills of minnows, silverside, and white perch (Olson, et al., 1941).

Recommendation: Water quality requirements for specifying the permissible limits of settleable solids and floating materials cannot be expressed quantitatively at present. Since it is known that even minor deposits may reduce productivity and alter the benthic environment, it is recommended that no materials containing settleable solids or substances that may precipitate out in quantities that adversely affect the biota should be introduced into estuarine or coastal waters. It is especially urgent that areas serving as habitat or nursery grounds for commercially important species (scallops, lobsters, oysters, clams, crabs, shrimp, halibut, flounders, demersal fish eggs and larvae, and other bottom forms) be protected from any infringement on natural conditions.

Tainting Substances

Substances found in industrial wastes are frequently responsible for objectionable or offensive tastes, odors, and colors of fish and shellfish. Even slight amounts of oil or petroleum products in bays and estuaries will impart an oil or kerosene flavor to mullet, mackerel, and other fishes and also to oysters, clams, and mussels making them unmarketable. Oysters collected in Louisiana waters polluted by crude oil retained a distinct flavor and odor associated with this type of pollution for several weeks after the escape of crude oil from wells and leaky barges had been stopped (Galtsoff, et al., 1935).

Anaerobic conditions associated with the deposit of sewage sludge on the bottom are accompanied by the production of hydrogen sulfide, a substance that causes black discoloration of bivalve shells and imparts an offensive flavor and odor to their flesh. In the waters receiving black liquor from Kraft pulp mills in the York River, Va., the gills and mantles of oysters developed a gray color. This condition also is found in oysters grown in waters receiving domestic sewage (Galtsoff, et al., 1957).

Contamination of water with copper results in the accumulation and storage of this metal far above its normal content in the tissues. The copper content of oyster flesh from uncontaminated waters off Cape Cod varied from 0.170 to 0.214 mg copper per oyster or from 8.21 to 13.77 mg per 100 g dry weight. In green colored oysters collected from adjacent areas only slightly contaminated with copper salts, the copper content in the flesh ranged from 1.27 to 2.46 mg per oyster or from 121.71 to 271 mg per 100 g dry weight (Galtsoff and Whipple, 1931; Galtsoff, 1964).

In a current study conducted at the Northeast Marine Health Sciences Laboratory, at Narragansett, R.I., Dr. B. H. Pringle (unpublished data) found that the average copper content of oysters collected from unpolluted areas along the east shore ranged from 20 to 80 mg/l, wet weight; oysters from areas known to be polluted contained from 124.5 to 392.0 mg/l wet weight. The copper content of sea water ranged between 0.0038 to 0.005 mg/l in areas not known to be polluted. In certain polluted places, concentrations as high as 0.019 mg/l were recorded.

Other metals are easily absorbed, stored, and concentrated by oysters in great excess of their concentration in sea water. Experimentally, it has been shown that iron and iodine can be absorbed within a relatively short time by oysters from water to which these metals have been added in excess. The flavor of so-called superiodized oysters produced before World War II in Arcachon, France, was pronounced because the iodine content of flesh was many times higher than that in untreated oysters (Galtsoff, 1964). The color of the oysters was not affected.

Green color of the gills of the European oyster in France and in the American oyster occasionally found in North Carolina and Chesapeake Bay is due to absorption of the blue-green pigment of the diatom, *Navicula*, present in large numbers on oyster grounds. The color is not associated with the increased copper content of flesh (Ranson, 1927).

Recommendation: To prevent the tainting of fish and other marine organisms, substances that produce tastes and off-flavors should not be present in concentrations above those shown to be acceptable by means of bioassays and taste panels. Experience has shown that test organisms should be exposed to the materials under test for 2 weeks at selected concentrations to determine the maximum concentration that does not produce noticeable off-flavors as determined by organoleptic tests. (Cooking should be done by baking the material wrapped in aluminum foil.)

Plant Nutrients and Nuisance Organisms

Plant nutrients and nuisance organisms are interrelated in many ways. There also are many other factors in the environment, such as temperature and salinity, that are closely correlated and, in many instances, seem to be contributing factors to nuisance organisms.

Man, through altering the hydrography of his environment by building dams and diverting waterflows from their natural courses, has produced conditions in many areas that have caused nuisance growths and brought about an imbalance of natural conditions. He also has enriched surface waters and created imbalances in dissolved materials and organisms through careless land management and by allowing the introduction of nutrients from sewers, food processing industries, fertilizer plants, feed lots, and farms. As a result, natural communities of aquatic life are altered and the functioning of these ecosystems often is changed severely or destroyed.

To maintain natural distribution, abundance, and interrelations of the aquatic biota, and to control unwanted growths, it is necessary to determine and maintain levels of dissolved materials required for this balance. This is an extremely difficult task, however, because there are a great many interrelated factors that contribute to the development of excessive populations of a species. Although a considerable amount of work has been done on the nutrition of aquatic organisms, most of this work has been done on a very few different species. Very little research has been done to determine what interaction of factors causes a shift in diversity or in the kinds of species that compose a community. For these reasons it is impossible to set any definite requirements. At this time the only meaningful thing that can be done is to develop guidelines.

Plant Nutrients: The increase of nutrients in the sea is accelerated by deposition of material derived from the land as sediments from the rivers, by settling and filling caused by water movements produced by tide or wind, and by biological activity. To date, no serious problems resulting from abnormal enrichment of nutrients have been identified in the open sea except perhaps locally around outfalls that extend several miles out to sea. With the increased disposal of wastes in the sea, this potential problem should be carefully watched.

Estuaries and tidal embayments have long been recognized as some of our most valuable and productive resources. They are the most ephemeral of the natural marine habitats and consequently most easily affected by man's activities. They serve as sinks for most of the organic and inorganic materials resulting from land erosion. Because of the lack of scouring and the nature of the sediments that occur in some areas, anaerobic conditions often develop in the beds of estuaries and bays. Increases in the deposition of suspended solids intensifies this condition. An excellent discussion of the role of sediments in an estuary is given by Carriker (1967).

Many industries and municipalities discharge nutrient-rich wastes into estuaries. Because of the nature of the estuary, these are recycled and accumulated over a period of time. Because of this recycling, effluents with low concentrations of nutrients may, in time, produce serious problems. The complete flushing of the estuary often takes many years. With controlled water discharges, this problem may become more severe.

Plant nutrients consist of many types of chemicals. For example, we have the chemicals commonly recognized as being important in plant nutrition such as nitrate, phosphate, sulfate, carbonate, calcium, magnesium, sodium, and potassium. There are also the so-called "trace elements" which are equally important but are required in small amounts such as iron, manganese, molybdenum, cobalt, zinc, etc. More recently the importance of organic compounds in plant nutrition has been recognized. These include vitamins, such as vitamin B_{12}, organic forms of nitrogen, such as urea, various amino acids, and amides, and the simple sugars, such as glucose.

The role of dissolved organic compounds in the nutrition of plants as well as animals appears to be important. Darnell (1967) refers to the aquatic medium as a "vegetable soup" to indicate its richness in dissolved organic materials. The work of Ryther (1954) points out that the organic forms of nitrogen are best utilized by the less desirable species (*Nannachloris atomus* and *Stichoccus sp.*). *Nitzschia*, a desirable diatom, often grows poorly in their presence. This is no doubt a major reason why sewage effluents often bring about the development of undesirable species.

If the increased nutrients in a system are well balanced, many species will have larger populations, the predator pressure will increase, and the productivity of the whole ecosystem will increase. If, however, the increased nutrients are of undesirable composition for most forms of aquatic life, or not in the correct ratio, excessive blooms of species with low predator pressures may develop. Examples of these are certain blue-green algae. Of course, environmental factors other than nutrients are important in the development of blooms. Any one important factor, such as temperature, light, or water mass stability, if limiting, may prevent blooms even though other conditions are suitable for their development. As a result, blooms sometimes do not develop even though most of the conditions are favorable.

Nuisance Organisms: Nuisance organisms in the marine environment are usually defined as those organisms which interfere with the use that man wishes to make of a particular water. Some examples are abnormally abundant growths of organisms that make bathing beaches unattractive, produce unpleasant odors, foul the bottoms of boats, spoil the esthetic appearance of water and the coastline, clog fishing nets, interfere with the flow of water within intake and effluent pipes, and interfere with navigation. This category of nuisance organisms should also include those organisms that interfere with the growth and reproduction of organisms important to man. For example, excessive populations of boring sponge or oyster drills, rooted and floating aquatics can interfere with the movement and reproduction of fish; bacteria and red tide organisms such as *Gymnodinium* and *Gonyaulax* may have toxic effects on other organisms, including man (Rounsefell and Nelson, 1966; Felsing, 1966).

The groups of organisms that may cause nuisances or become severe pests include algae (including red tide organisms), coelenterates, sponges, mollusks, such as oyster drills and mussels, and crustacea. These organisms are commonly encountered in the natural marine environment. Organisms may become nuisances because of excessive growth and changes in distribution patterns and predator-prey relationships. The main causative factors are excessive and, often, imbalanced nutrients, considerable changes in the natural regimes of temperature, turbidity, and salinity, and changes in current patterns.

In some instances, nuisance growths seem to be directly related to the nutrients that are available. In other situations, nuisance growths may not be directly affected by artificial enrichment, so far as we know, and seem to be more strongly affected by changes in the temperature, salinity, or turbidity. Included here are various fouling organisms: barnacles, mussels and other mollusks, polyzoa tube worms, marine borers, and pests to useful marine products (oyster drills, boring sponges, crabs, parasitic fungi, and protozoans), and swarms of jellyfish, which make bathing in some coastal waters hazardous during certain seasons.

The effect of increased nutrients may be an increase in the populations of certain species already present in the environment and a decrease of species that are not tolerant of such nutrients. Examples of such conditions are the increase of *Enteromorpha* and sea lettuce, *Ulva lactuca*, in the zone of mineralization of sewage which occurs in some areas of the lower Potomac. In areas of higher salinity, abundant growths of *Ascophyllum* often occur in waters containing mineralized effluents from sewage treatment plants. In Biscayne Bay, Fla., the following organisms became abundant under such conditions: the flowering plants, *Halophila baillonis* and *Diplanthera wrightii;* and the echinoderm, *Amphioplus abditus*. Under heavy organic enrichment, the algae, *Gracilaria blodgettii* and *Agardhiella tenera*, the worm, *Diopatra cupera*, and the amphipods, *Erichthonius brasiliensis* and *Corophium acherusicum*, became very common (McNulty, 1955).

In other cases, an imbalanced organic enrichment together with changes in temperature and salinity brings about an almost complete change in the species composing an aquatic community plus excessive growths of some species. An excellent example of this type has been described by Ryther (1954) in his studies of Moriches Bay and Great South Bay, Long Island. In this area, duck farm wastes enrich the bay waters with organic compounds that produce a low nitrogen-to-phosphorus ratio. At the times of the largest algal blooms, low salinities and high temperatures exist in the area. As a result, desirable marine diatom species of *Nitzschia* which prefer cool water (5 to 25 C), nitrates, and nitrites as a source of nitrogen, and are not benefited by a low N/P ratio (5:1) were replaced by *Nannochloris atomus* and *Stichococcus sp.* These species can grow well in nitrates, nitrites, ammonia, urea, uric acid, and cystine, and prefer a N/P ratio of 5:1. As Ketchum (1967) points out, these weed species are undesirable food sources and the natural productivity of the estuary is destroyed. Ketchum also points out that the greatest amount of plankton does not always occur in the waters of greatest enrichment. This is because the development of a maximum standing crop of phytoplankton is also governed by the concentration of predators, stability of the water column, transparency of the water, etc.

Nutrient imbalance may affect the ratio of inorganic phosphate to total phosphorus, here defined as the sum of inorganic, organic, and particulate phosphorus. It is known from the work of Pomeroy (1960) and others that inorganic phosphorus is rapidly taken up by actively growing plants. At the same time, inorganic phosphorus is regenerated as a result of bacterial degradation and excretion by animals. The net effect over the short run is to produce a steady state between the various fractions of phosphorus in the environment. There should be some ratio of inorganic to total phosphorus in the euphotic zone that would be characteristic of a balanced nutrient regime and this ratio should be lower than the same ratio for the imbalanced system in which inorganic phosphorus can accumulate.

Data from Moriches Bay and Great South Bay on Long Island, Charlestown Pond, R.I., the North Atlantic, and the North Pacific have been examined. In the obviously polluted portion of Moriches Bay, the inorganic total phosphate ratio generally exceeds 0.6, while the Charlestown Pond, an uncontaminated estuary of similar characteristics to Moriches Bay, this ratio was less than 0.4. In the open ocean at high latitudes and in the winter when phytoplankton density is low, the fraction of inorganic phosphorus may increase to 0.65 or thereabout.

Recommendation: The ecological factors most often associated with nuisance growths are changes in the natural temperature and salinity cycles and increases in nutrients. The change in any of these factors may directly or indirectly affect the response of the organisms to other factors. Increase or decrease in current and, indirectly, its effect on available nutritional materials have also been found to be important.

To maintain a balance among nutrients and a balanced biota most conducive to the production of a desired crop, it is recommended that:

(1) No changes should be made in the basin geometry, current structure, salinity, or temperature of the estuary without first studying the effects on aquatic life. For example, these studies should be made before dams are erected, water diversion projects are constructed, or dredge and fill operations carried out.

(2) The artificial enrichment of the marine environment from all sources should not cause any major quantitative or qualitative alteration in the flora. Production of persistant blooms of phytoplankton, whether toxic or not, dense growths of attached algae or higher aquatics or any other sort of nuisance that can be directly attributed to nutrient excess or imbalance should be avoided. Because these nutrients often are derived largely from drainage from land, special attention should be given to correct land management in a river basin and on the shores of a bay to prevent erosion.

(3) The naturally occurring atomic ratio of NO_3-N to PO_4-P in a body of water should be maintained. Similarly, the ratio of inorganic phosphorus (orthophosphate) to total phosphorus (the sum of inorganic phosphorus, dissolved organic phosphorus, and particulate phosphorus) should be maintained as it occurs naturally. Imbalances have been shown to bring about a change in the natural diversity of the desirable organisms and to reduce productivity.

Toxic Substances

Relatively few of the many substances recognized as potential toxic pollutants of the marine environment have been studied sufficiently to enable us to define their maximum allowable concentrations. Specific pollutants and classes of pollutants are discussed in terms of current knowledge. In some cases, data are adequate to set definite criteria, while in others, criteria are educated guesses at best and can serve only as temporary guidelines.

Lethal concentrations of some persistent substances as determined by acute toxicity tests are so low that we are not justified in allowing their deliberate introduction into the natural environment. On the other hand, a few waste products appear to offer little threat to the marine environment because of their rapid degradation and dispersal.

Our concern is not primarily with what polluting substances are present, but whether or not they are present in sufficiently large amounts to cause deleterious effects on the biota and the environment. Many naturally occurring substances, including clean fresh water, would be toxic if discharged into the estuarine and coastal marine environment in sufficiently large amounts.

Determination of the toxicity of known and unknown effluents, either simple or complex mixtures, can best be made by determining the reactions of endemic fauna exposed to them at levels that might be expected in receiving waters. Chemical assays may determine the presence of such pollutants at levels as low as nanograms per liter, but biological systems may be affected by even smaller amounts. Many animals have the ability to accumulate toxic residues of substances present in the environment in only trace amounts until body residues are large enough to cause damage when released internally through normal metabolic processes. Animals differ in their sensitivity to the same toxicant and it is essential that toxicity data be related, in the final analysis, to animals of economic importance.

A fundamental concept in attacking the pollution problem is the assumption that effluents containing foreign materials are harmful and not permissible until laboratory tests have shown the reverse to be true. It is the obligation of the agency producing the effluent to demonstrate that it is harmless rather than require pollution abatement agencies to demonstrate that the effluent is causing damage.

Specific methods are suggested here for the determination of the toxicity of proposed effluents. While certain procedures are desirable, they are not always reasonable and certain permissible alternatives are also given.

Basic Bioassay Test: The basic bioassay test shall consist of a 96-hour exposure of an appropriate organism, in numbers adequate to assure statistical validity, to an array of concentrations of the substance, or mixture of substances, that will reveal the level of pollution that will cause (1) irreversible damage to 50 percent of the test organisms, and (2) the maximum concentration causing no apparent effect on the test organisms in 96 hours. Tests should be conducted, when possible, in a "flow-through" system so that the organisms are exposed continuously to a fresh solution of the test material appropriately diluted with water of the same quality as that at the site of the proposed discharge. Adequate safeguards should be taken to insure that the test will be conducted under the least favorable environmental conditions that are allowable in the natural environment. Tests should be conducted at water temperatures typical of the mean of maximum daily temperatures during critical periods at the proposed effluent discharge site.

Test organisms should be selected either on the basis of their economic importance in the area receiving the discharge and their sensitivity or on the basis of their importance in the food web of economically important animals. In the event that organisms meeting these criteria are not suitable or available for the confined conditions of the tests, substitute forms endemic to the area may be utilized. Appropriate tests must be undertaken to demonstrate the relative sensitivity of economically important species and substitute species to the test material so that meaningful interpretations of the data can be made.

Application Factor: It is recognized that the most obviously deleterious effect of toxic substances is increased mortality. More subtle changes such as reduced growth, lowered fecundity, altered physiology, and induced abnormal behavior patterns may have more disastrous effects on the continued existence of the species. Evaluations of such sublethal effects generally will provide more meaningful guidelines.

It is recognized that there should be an application factor for each waste or material and that these factors may vary widely for these different wastes and materials. The concept and use of application factors is defined and discussed at length in the toxicity portion of the section on water quality requirements for fresh water organisms. Due to a lack of knowledge of application factors for specific wastes and materials, a single application factor to be applied to all wastes is being suggested at this time. This application factor may require a lower concentration than is necessary in some instances, particularly for those materials that are subject to biological degradation, but it is known that it is not restrictive enough for some materials. Ideally, the determination of application factors should be the result of studies for the determination of safe levels of potential toxicants under long-term or continuous exposure. The application factor is the concentration of a material or waste that is not harmful, divided by the 96-hour TL_m value for that material. A few application factors have been so determined at the Bureau of Commercial Fisheries Laboratory at Gulf Breeze, Fla. (unpublished data). In the future, as application factors are determined for specific substances, they will replace the recommendation for the generalized application factor for these particular materials or wastes. It is clearly understood that as additional data become available recommendations on water quality requirements will be changed so that they conform with the new knowledge.

Biological Magnification: Biological magnification is an additional chronic effect of toxic pollutants (such as heavy metals, pesticides, radionuclides, bacteria, and viruses) which must be recognized and examined before clearance can be given for the disposal of a waste product into natural waters. Many animals, and especially shellfish such as the oyster, have the ability to remove from the environment and store in their tissues substances present at nontoxic levels in the surrounding water. This process may continue in the oyster or fish, for example, until the body burden of the toxicant reaches such levels that the animal's death would result if the pollutant were released into the bloodstream by physiological activity. This may occur, as in the case of chlorinated hydrocarbon pesticides (such as DDT and endrin) stored in fat depots, when the animals food supply is restricted and the body fat is mobilized. The appearance of the toxicant in the bloodstream causes the death of the animal. Equally disastrous is the mobilization of body fat to form sex products which may contain sufficiently high levels of the pollutant so that normal development of the young is impossible.

The biological magnification and storage of toxic residues of polluting substances and microorganisms may have another serious after effect. Herbivorous and carnivorous fish at lower trophic stages may gradually build up DDT residues of 15 to 20 mg/l without apparent ill effect. Carnivorous fish, mammals, and birds preying on these contaminated fish may be killed immediately or suffer irreparable damage because of the pesticide residue or infectious agent.

In the final analysis, laboratory tests alone are not sufficient to assess completely the toxic effects of a substance. These data must be interpreted in combination with field observations. Criteria established under the artificial conditions of laboratory tests will probably require adjustment in the light of later and more prolonged field observations.

Recommendation: In the absence of toxicity data other than the 96-hour TL_m, an arbitrary application factor of $^1/_{100}$ of this amount shall be used as the criterion of permissible levels.

Additional chronic exposure tests will be conducted within a reasonable period to demonstrate that the estimated maximum safe levels as indicated by the

96-hour TL_m and the application factor do not, in fact, cause decreases in productivity of the test species during its life history.

Monitoring the Marine Environment: The chief problem in monitoring the marine habitat for pollution lies in the fact that the discharge of toxic materials may be intermittent. This is not necessarily true, but it means that water samples collected periodically reflect only the conditions at the time they were collected. Significantly higher or lower levels of pollution may have existed between sample collections. A second major factor for consideration is that trace amounts of pollutants or effluent mixtures toxic to the biota may not be readily susceptible to chemical analysis. For these reasons, the analysis of resident biota for abnormal changes offers a better tool for interpreting environmental fluctuations.

Mollusks are being collected for analysis at monthly intervals in estuaries on both the Atlantic and Pacific coasts (Butler, 1966 a, b). Analysis of resident populations by electron capture, gas chromatographic techniques reveal changes in residues of 11 of the more common organochloride pesticides which oysters, mussels, and some species of clams readily store. These methods are useful for rapid surveys of recent pollution. By appropriate spacing of samples in time and location, it has been possible to pinpoint sources of pollution.

It is suggested that a monitoring system of this type, appropriately expanded to include fish and plankton, would quickly identify areas where pollution problems exist. Suitable analytical techniques are available to make these samples equally useful for the identification of pollution by heavy metals and other toxic substances.

Monitoring for the presence of organophosphorous materials is feasible, but less specific for individual toxic compounds. This group of pesticides exerts its toxic effect on living systems by inhibiting the enzyme acetylcholinesterase, which is essential to conduction in nerve fibers. The nervous tissue of fish and some invertebrates, appropriately analyzed, reveals whether the organism has been exposed to organophosphorous materials within the past 2 to 4 weeks (Holland, et al., 1967). Identification of such changes can be made before toxicant levels are high enough to cause serious mortalities.

A particularly efficient nonspecific method for monitoring changes in the estuarine habitat is based on the periodic collection of sedentary animals and plants which have attached themselves to artificial cultch plates. Squares of asbestos cement boards placed in strategic locations will be utilized by resident biota as a habitat. At 30-day or shorter intervals these plates can be changed, the organisms enumerated, volumetrically measured or chemically assayed, and an index of their relative abundance obtained (Butler, 1954).

Such plates have been maintained for nearly 20 years at one laboratory in Florida (Butler, 1965), and they supply detailed information on the relative productivity of the environment in relation to hydrologic changes. They will be equally useful as monitors of newly introduced pollutants in this area. The monitoring method of choice—and there are others besides the ones suggested—will depend on the specific environment and the animals of particular interest. No one method will be adequate and a combination of methods should provide the most information in the shortest time period.

Pesticides: Pesticides may be described as natural and synthetic materials used to control unwanted or noxious animals and plants. They exert their effect as contact or systemic poisons, as repellents, or in some cases as attractants. It is convenient to classify them according to their major usage such as fungicides, herbicides, insecticides, fumigants, and rodenticides. Although data are not available as to the total amount of pesticides used in the United States, total production figures (including exports) show that more than 875 million pounds were produced in 1965. This represents an increase of approximately 10 percent over 1964, and more than a fivefold increase in the past two decades. In recent years, the use of herbicides has increased relatively more rapidly than that of other pesticides. In 1964, more than 100 million acres of the continental United States were treated with some kind of pesticide. The trend in pesticide production is towards the manufacture of more granular formulations. This physical adsorption of the pesticide on clay particles makes possible better control during application and should result in less dissipation of the chemical into atmosphere and into nontarget areas.

Despite better control of pesticide applications, their dispersal in drainage systems and possible eventual accumulation in estuaries makes our coastal fisheries especially vulnerable to their toxic effects. Estuarine oyster populations, juvenile shrimp, crab, and menhaden, for example, all occupy the habitat where fresh and salt water mix and where deposition of river silt with its load of adsorbed pollutants takes place. Laboratory tests show that these economically important animals are especially sensitive to the toxic effects of low levels of pesticides. Oysters, for example, will exist in the presence of DDT at levels as high as 0.1 mg/l in the environment. But at levels 1,000 times less (0.1 μg/l), oyster growth or production would be only 20 percent of normal, shrimp populations would suffer a 20-percent mortality, and menhaden would suffer a disastrous mortality. Some insecticides are toxic enough to kill 50 percent or more of shrimp populations after 48 hours exposure to concentrations of only 30 to 50 nanograms per liter of the compound.

Pesticides may be classified by their chemical affinities and a large number of economically important insecticides are chlorinated hydrocarbon compounds. These include the well-known DDT and aldrin-toxaphene group. Typically, these are persistent compounds, but they may be degraded by living systems into less toxic metabolites. As residues in soil and marine sediments, they may persist unchanged for many years and consequently present a continuing threat to animal communities. As a general rule, the acute toxicity of this group of pesticides increases with the level of metabolic activity so that their presence may cause two or three times more damage in summer than in winter months.

The organophosphorous pesticides are also primarily insecticides. Typically, they hydrolyze or break down into less toxic products much more readily than the organochloride compounds. Practically all persist for less than a year, while some last only a few days in the environment. Most of them are degraded rather quickly in warm water and consequently are more hazardous to aquatic animals at winter rather than summer temperatures. They exhibit a wide range of toxicity, both more and less damaging to marine fauna than the organochlorides. They are usually preferable as control agents because of their relatively short life.

Other major chemical categories including the carbamates, arsenicals, and 2,4-D and 2,4,5-T compounds are generally, but not necessarily, less toxic to marine biota.

Pesticides registered for uses which might permit their dispersal into the marine environment must be evaluated for their toxic effect on oysters, fish, and shrimp. Consequently, there is a considerable amount of information on the 48 or 96-hour TL_m values of these compounds. Unfortunately, information is still lacking on their long-term effects at sublethal levels on the productivity of economically important marine species.

The extreme sensitivity of marine crustaceans, such as crabs, lobsters, and shrimp, to the array of insecticides is to be expected because of their phylogenetic relationship with terrestrial arthropods. In general, shrimp are also much more sensitive than fish or oysters to the other pesticides. This fact and their economic importance make shrimp a valuable yardstick for establishing safe levels of pesticides that might be expected as toxicants in the marine environment.

A much broader spectrum of pesticide pollutants can be anticipated in the fresh water (salinity <0.5 ‰) zones of tidal estuaries. Fresh water criteria listed in another section will apply under these circumstances.

Recommendation: The pesticides are grouped according to their relative toxicity to shrimp, one of the most sensitive groups of marine organisms. Criteria are based on the best estimates in the light of present knowledge and it is expected that acceptable levels of toxic materials may be changed as the result of future research.

Pesticide group A.—The following chemicals are acutely toxic at concentrations of 5 μg/l and less. On the assumption that 1/100 of this level represents a reasonable application factor, it is recommended that environmental levels of these substances not be permitted to rise above 50 nanograms/l. This criterion is so low that these pesticides could not be applied directly in or near the marine habitat without danger of causing damage. The 48-hour TL_m is listed for each chemical in parts per billion (μg/l).

Organochloride pesticides

Aldrin	0.04
BHC	2.0
Chlordane	2.0
Endrin	0.2
Heptachlor	0.2
Lindane	0.2
DDT	0.6
Dieldrin	0.3
Endosulfan	0.2
Methoxychlor	4.0
Perthane	3.0
TDE	3.0
Toxaphene	3.0

Organophosphorous pesticides

Coumaphos	2.0
Dursban	3.0
Fenthion	0.03
Naled	2.0
Parathion	1.0
Ronnel	5.0

Pesticide group B.—The following types of pesticide compounds generally are not acutely toxic at concentrations of 1 mg/l or less. It is recommended that an application factor of 1/100 be used and, in the absence of acute toxicity data that environmental levels of not more than 10 μg/l be permitted.

Arsenicals
Botanicals
Carbamates
2,4-D compounds
2,4,5-T compounds.
Phthalic acid compounds.
Triazine compounds.
Substituted urea compounds.

Other pesticides.—Acute toxicity data are available for approximately one hundred technical grade pesticides in general use not listed in the above groups. These chemicals either are not likely to reach the marine environment, or, if used as directed by the registered label, probably would not occur at levels toxic to marine biota. It is presumed that criteria established for these chemicals in fresh water will protect adequately the marine habitat. It should be emphasized that no unlisted chemical should be discharged into the estuary or coastal water without preliminary bioassay tests and the establishment of an adequate application factor.

Heavy Metals: Heavy metal salts in solution may constitute a very serious form of pollution because they are stable compounds, not readily removed by oxidation, precipitation, or any other natural process. A characteristic feature of heavy metal pollution is its persistence in time as well as in space for years after the pollutional operations have ceased.

The number of substances that may be described as "poisonous" is very large and they vary enormously in the degree of their effect. For man and other air-breathing animals, the threshold dose of a toxic material generally means the maximum quantity that can be taken without causing death. For aquatic animals living in a water environment containing a toxic substance, the situation is somewhat different. Instead of receiving an absolute quantity at one time, they are being continually exposed to a given concentration of the toxic material. This is similar to a man regularly drinking water containing lead or breathing air containing a noxious gas or vapor. It is not surprising, therefore, that the student of pollution problems turns his attention toward the concentration of the poison he is investigating and the manner in which the effect is related to this, rather than to the absolute amount required to harm or kill. Animals have the ability to eliminate poisons at least to some degree or even to destroy them. Their ability to do this at a rate permitting survival depends on the concentration of the toxic material to which they are exposed.

One of the characteristics of living cells is their ability to take up elements from a solution against a concentration gradient. This is perhaps most obvious for marine organisms, especially for autotrophic algae which obtain all their nutrients directly from seawater. The ability of marine organisms to concentrate elements above that level found in their environment has been recognized for some time. The following points should be noted in relation to their concentrating ability.

(1) All elements are concentrated to a degree with the exception of chlorine, which is rejected, and sodium, which is weakly rejected. The concentration factors are of the order of one for bromine, fluorine, magnesium, sodium, and sulfur, and higher for all other elements.

(2) Among cations (including metallic elements such as iron, which may exist as colloids in the sea), the order of affinity for living matter is, generally: tetravalent and trivalent elements>divalent transition elements>divalent group II-A metals>univalent group I metals. The tetravalent and trivalent subgroup have rather different affinities for plankton and brown algae.

plankton: Fe>Al>Tl>Cr, Si>Ga
brown algae: Fe>La>Cr>Ga>Li>Al>Si

Similar differences are found between these organisms in their affinities for the divalent transition metals.

plankton: Zn>Pb>Cu>Mn>Co>Ni>Cd
brown algae: Pb>Mn>Zn>Cu, Cd>Co>Ni

Of interest is the affinity of both organisms for lead, which has no known biological function.

It is clear that the heavier elements in these groups tend to be more readily taken up than the lighter ones, which may be connected with their greater, ease of polarization.

(3) The order of affinity of living matter for anions is:

nitrate>trivalent anions>divalent anions>univalent anions

It is probable that most polyvalent metallic elements are more or less chelated by organic matter.

The main features of the uptake of ions by cells can be accounted for by assuming that another process operates apart from simple diffusion. This process is called active uptake and is closely linked with metabolic activities within the cell. The metabolic processes provide the energy necessary for the uptake against a concentration gradient. Active uptake has a larger temperature coefficient than does uptake by diffusion. In long-term experiments, the effect of temperature is probably complicated by increased rates of growth, cell division, and so on. Active uptake requires oxygen and occurs only in cells which are respiring freely. Substances which inhibit respiration also inhibit uptake of ions. The rate of uptake of ions may be limited either by the rate of exchange at the cell membrane or by bulk phase diffusion inside the cell. The former is usually limiting for ions present at low external concentration and the latter for ions at high external concentrations. It has been suggested that bulk phase diffusion limits the rates of uptake of most cations. There appears to be at least two active transport systems in addition to the diffusion processes. A large number of theories have been advanced to explain active transport. One of the most popular is the carrier hypothesis. Accordingly, the ions are transported across membranes as chelates with metabolically produced organic molecules.

Uptake by invertebrate animals.—The most primitive animals, the unicellular protozoa, take up ions from solution by diffusion in the same ways as do algae. Many marine species have vacuoles and these are able to open at intervals and extrude fluid from the cell. The vacuole regulates the osmotic pressure of the cell and thus controls its volume.

Multicellular invertebrate animals can be divided into two groups as far as uptake is concerned: those with permeable integuments and those without. The majority of marine invertebrates (colenterates, annelids, mollusks, and echinoderms) have soft bodies with permeable integuments through which ions can diffuse freely. In this situation, the body fluid or blood is quite similar to sea water in composition. The gills of mollusks are coated with a layer of complex carbohydrate sulfates which may function as ion exchangers. The gills of marine Crustacea, which have hard impermeable carapaces, are fully permeable to water and salts.

Mode of toxic action.—An element is said to be toxic if it injures the growth or metabolism of an organism when supplied above a certain concentration. All elements are toxic at high concentrations and some are notorious poisons even at low concentrations. For example, the essential micronutrient, copper, which is a necessary constituent of all organisms, is highly toxic at quite small concentrations. The other essential micronutrients are also toxic when supplied in excess, though not all in such striking fashion. There is an optimum range of concentration, which is sometimes quite narrow, for the supply of each element to each organism.

When excessive amounts of an element are fed to an organism, they frequently cause death. The usual measure of the amount required to cause death is called the LD_{50}. This is the amount which, when fed to each individual in a population, kills half of the population. The LD_{50} is an imprecise measure unless it is qualified by specifying:

(1) The chemical state of the element.
(2) The means of feeding.
(3) The age or developmental stage of the organism.
(4) The time elapsed between feeding and death.

The most important mechanism of toxic action is thought to be the poisoning of enzyme systems. The more electronegative metals, notably copper, mercury, and silver, have a great affinity for amino, imino, and sulfhydryl groups which are doubtless reactive sites on many enzymes. These metals are readily chelated by organic molecules. We thus have discovered attempts to correlate metal toxicities with such factors as their electronegativities, the insolubility of their sulfides, or the order of stability of their chelated derivatives:

(1) Order of electronegativities of some divalent metals: Hg>Cu>Sn>Pb>Ni>Co>Cd>Fe>Zn>Mn>Mg>Ca>Sr>Ba
(2) Order of stability products of the sulfides: Hg>Cu>Pb>Cd>Co>Ni>Zn>Fe>Mn>Sn>Mg>Ca
(3) Order of stability of chelates: Hg>Cu>Ni>Pb>Co>Zn>Cd>Fe>Mn>Mg>Ca.

It appears likely that all the divalent transition metals, as well as the other electronegative metals, that form insoluble sulfides, such as Ag, Mo, Sb, Tl, and W, are poisons by virtue of their reactivity with proteins and especially with enzymes. In view of the large number of enzymes in living cells, the variations in toxicity indicated above are hardly surprising. Studies have shown that metals giving rise to similar toxic effects may be acting on quite unrelated enzymes and also many more atoms of metal are absorbed by an inactivated enzyme than are required to block the reactive sites. Other modes of toxic action are:

(1) Substances behaving as antimetabolites. This might be arsenate and chlorate occupying sites for phosphates and nitrates, respectively. (Fluoride, borate, bromate, permanganate, antimonate, selenate, tellurate, tungstate, and beryllium.)
(2) Substances forming stable precipitates or chelates with essential metabolites. (Al, Be, Sc, Ti, Y, Zr, reacting with phosphate, Ba with sulfate, or Fe with ATP.)
(3) Substances catalyzing the decomposition of essential metabolites. (La and other lanthanide cations decompose ATP.)
(4) Substances combining with the cell membrane and affecting its permeability. (Au, Cd, Cu, Hg, Pb, U.) These elements may affect transport of sodium, potassium, chlorine, or organic molecules across membranes or even rupture them.
(5) Substances replacing structurally or electrochemically important elements in the cell and then failing to function. (Li replacing Na, Cs replacing K, or Br replacing Cl.)

Metal-organic compounds may be either more toxic than the metal ion (ethyl mercuric chloride) or much less so (cupric ion and copper salicylaldoxime).

Silver.—Silver is present in seawater in a concentration of about 0.0003 mg/l. It is found in marine algae at concentrations up to 0.25 mg/l and in marine mammals in the range of 1 to 3 mg/l (Vinogradov, 1953). It is highly toxic to plants and mammals.

Arsenic.—Arsenic is found to a small extent in nature in the elemental form. It occurs mostly in the form of arsenites of true metals or as pyrites.

Its major commercial use is for pesticides (insects, weeds, fungi). Arsenic is cumulative in the tissues of many organisms and, therefore, it eventually exerts its effects even though the environmental level is low. It has been demonstrated to be a possible carcinogen in water.

Arsenic is found in seawater at a concentration of about 0.003 mg/l. It has been found in marine plants at concentrations up to 30 mg/l and is highest in the brown algae. It is found in marine animals in a range of 0.005 to 0.3 mg/l. It is accumulated by coelenterates, some mollusks, and crustaceans (Vinogradov, 1953). It is moderately toxic to plants and highly toxic to animals especially as AsH_3.

Arsenic trioxide, which also is exceedingly toxic, was studied in concentrations of 1.96 to 40 mg/l and found to be harmful to fish or other aquatic life. Work by the Washington Department of Fisheries (1944) on pink salmon has shown that at a level of 5.3 mg/l of As_2O_3 for 8 days was extremely harmful to this species. Ellis (1937), using the same compound on mussels at a level of 16 mg/l, found it to be quite lethal in 3 to 16 days. Surber and Meehan (1931) carried out an extensive study on the toxicity of As_2O_3 to many different fish food organisms. Their results indicated that important fish food organisms can tolerate an application rate of 2 mg/l of As_2O_3. The amount actually in the water is considerably less.

Cadmium.—The elemental form of cadmium is insoluble in water. It occurs largely as the sulfide which is often an impurity in zinc ores.

Cadmium is found in seawater at a level of less than 0.08 mg/l. Its level in marine plants is approximately 0.4 mg/l, while in marine animals a range of 0.15 to 3 mg/l has been found. It is lowest in the calcareous tissues and is accumulated within the viscera of the mollusk, *Pecten novazetlandicae* (Brooks and Rumsby, 1965). Cadmium is moderately toxic to all organisms and it is a cumulative poison in mammals.

Cadmium is used widely industrially to alloy with copper, lead, silver, aluminum, and nickel. It is also used in electroplating, ceramics, pigmentation, photography, and nuclear reactors. Cadmium salts sometimes are used as insecticides and antihelminthics. The chloride, nitrate, and sulfate of cadmium are highly soluble in water. The carbonate and hydroxide are insoluble, thus cadmium will be precipitated at high pH values.

Most quantitative data on the toxicity of cadmium are based on specific salts of the metal. Expressed as cadmium, these data indicate that the acute lethal level for fish varies from about 0.01 to about 10 mg/l depending on the test animal, the type of water, temperature, and time of exposure. Cadmium acts synergistically with other substances to increase toxicity. Concentrations of 0.03 mg/l in combination with 0.15 mg/l zinc causes mortality of salmon fry (Hublou, et al., 1954).

Pringle (in press), in a study of adult American Eastern oysters, *Crassostrea virginica,* found an 8-week TL_m value of 0.2 mg/l of $Cd^{++}[Cd(NO_3)_2]$ and a 15-week TL_m value of 0.1 mg/l.

The most obvious effect, in addition to lethality, was lack of shell growth. A similar study on the clam, *Mercenaria mercenaria,* indicated that a much longer period of exposure at the same concentration was required to kill half of the test organisms.

Chromium.—Chromium is found in seawater at a concentration of 0.00005 mg/l. Marine plants contain approximately 1.0 mg/l while marine animals contain chromium within a range of 0.2 to 1.0 mg/l. Chromium compounds may be present in wastes from many industrial processes or they may be discharged in chromium-treated cooling waters. The toxicity of chromium varies with the species, temperature, pH, its valence, and synergistic or antagonistic effects (especially with hardness). Most evidence points to the fact that under long-term exposure the hexavalent form is no more toxic towards fish than the trivalent form. Doudoroff and Katz (1953), studied the effect of $K_2Cr_2O_7$ on mummichaugs and found that they tolerated a 200 mg/l level in sea water for over a week.

The effects of hexavalent chromium on photosynthesis by the giant kelp, *Macrocystis pyrifera,* were as follows: at 1 mg/l chromium, photosynthesis was not diminished by 2 days contact. It was reduced 10 to 20 percent by 5 days contact and 20 to 30 percent after 7 to 9 days. The concentration of chromium required to cause a 50-percent inactivation of photosynthesis in 4 days was estimated at 5 mg/l (Clendenning and North, 1958. 1960; North and Clendenning, 1958, 1959).

Haydu (unpublished data) studied oyster mortalities and his results point out the long-term effects of low concentrations of chromium, molybdenum, and nickel. The levels of all three metals were in the range of 10 to 12 μg/l over a 2-year period. In addition, his data indicated that there were seasonal variations. The mortalities at these levels increased with an increase in temperature. Approximately 63 to 73 percent of the mortalities occurred in the period of May through July, perhaps due to increased physiological activity (increased feeding and higher pumping rates).

This study substantiates the available evidence indicating that as the environmental level of these metals increases, the ingestion-elimination balance is upset, causing accumulation to take place.

Raymont and Shields (1964), in studies with the small prawn, *Leander squilla*, found a threshold level of a little less than 5 mg/l Cr. Thus, at chromium concentrations ranging from 10 to 80 mg/l Cr, 100-percent mortality occurred in 1 week; at 5 mg/l Cr no deaths occurred in 1 week although a few animals died over the subsequent 21 days. Larger prawns of the same species appeared to be considerably more resistant to chromium poisoning. The threshold was about 10 mg/l Cr. Raymont and Shields in additional experiments on the toxicity of chromium to crustaceans (the shore crab, *Carcinus maenas*), indicated that chromium concentrations above 50 mg/l (Na_2CrO_4) were definitely toxic for a period of exposure of 12 days. At 60 mg/l Cr, 50-percent mortality occurred after 12 days. At 40 mg/l Cr, 9 percent died within 12 days, while at 20 mg/l, an 8-percent mortality was observed. In studies on the marine polychaete worm, *Nereis virens*, these same investigators working in the range of 2 to 10 mg/l Cr found that there was heavy mortality with all solutions in 2 to 3 weeks. The threshold of toxicity appears to be at about 1.0 mg/l Cr level.

Pringle (in press), in experiments using a well-controlled, flow-through system and chromium concentrations of 0.1 and 0.2 mg/l ($Na_2Cr_2O_7$), showed the average weekly mortality to be approximately 1 percent over a 20-week period. This was about the same as that for the sea water controls.

Copper.—Copper is found in seawater at a level of 0.003 mg/l. It is found in marine plants at about 11 mg/l, while marine animals are found to contain 4 to 50 mg/l. It is accumulated by some sponges and is essential for the respiratory pigment in the blood of certain annelids, crustacea, and mollusks. In excess, it is highly toxic to algae, seed plants, and to invertebrates and moderately toxic to mammals. Copper is not considered to be a cumulative systemic poison like lead or mercury.

The toxicity of copper to aquatic organisms varies significantly not only with the species but also with the physical and chemical characteristics of the water. Copper acts synergistically with zinc, cadmium, and mercury, yet there is a sparing action with calcium.

Barnacles and related marine fouling organisms were killed in 2 hours by 10 to 30 mg/l copper. Clarke (1947) showed that the mussel, *Mytilus edulis*, was killed in 12 hours by 0.55 mg/l. Lobsters transferred to tanks lined with copper after living in aluminum, stainless steel, and iron tanks for 2 months, died within 1 day. Copper is concentrated by plankton from surrounding water in ratios of 1,000 to 5,000 or more (Krumholz and Foster, 1957).

Concentrations of copper above 0.1 to 0.5 mg/l were found to be toxic to oysters by Galtsoff (1932). The 96-hour TL_m for oysters was estimated at 1.9 mg/l (Fujiya, 1960). Oysters cultured in waters containing 0.13 to 0.5 mg/l accumulated copper in their tissues and became unfit as a food substance. Pringle (in press) found the soft clam, *Mya arenaria*, extremely sensitive to copper. At a concentration of 0.5 mg/l, 100-percent mortality took place in 3 days. Using a 0.2 mg/l concentration at 10 and 20 C, all clams died within 23 days at the lower temperature, while at the higher temperature all succumbed in 6 to 8 days. When 0.1 mg/l Cu at 20 C was used, all animals died in 10 to 12 days. Raymont and Shields (1964) in studies with the marine polychaete worm *Nereis*, showed that a concentration of 1.5 mg/l Cu was lethal in 2 to 3 days, and concentrations exceeding 0.05 mg/l Cu were lethal in approximately 4 days.

Clendenning and North (1958, 1960) and North and Clendenning (1958, 1959) evaluated the effect of copper (from the chloride and sulfate salts) on the rate of photosynthesis of the giant kelp, *Macrocystis pyrifera*. With 0.1 mg/l of copper, net photosynthesis was inhibited by 50 percent in 2 to 5 days and 70 percent in 7 to 9 days. Visible injury appeared in 10 days. Copper was slightly less toxic than mercury but more so than nickel, chromium, lead, or zinc. Marvin, Lansford, and Wheeler (1961) found 0.05 mg/l Cu toxic to *Gymnodinium breve* (red tide organism).

Mercury.—Mercury is found in seawater at a level of 0.00003 mg/l. It is found in marine plants at approximately 0.03 mg/l.

Irukayama (1966) reported on a mercurial pollution incident in Japan, which was first recognized in 1953. A severe neurological disorder resulted in the area of Minamata Bay as a result of eating fish and shellfish from these waters. Many species of animals including waterfowl were succumbing to the "disease" called Minamata disease. Clinical features were cerebellar ataxia, constriction of visual fields, and dysarithia. Pathological findings were regressive changes in the cerebellum and cerebral cortices. Investigation through 1965 suggested that the main cause was the spent factory waste of the Kanose Factory upstream from the Minamata Bay area. Methyl mercury compounds, waste byproducts from the acetaldehyde synthesis process, were being discharged and concentrated especially in shellfish.

Ukeles (1962) made a study of pure cultures of marine phytoplankton in the presence of toxicants. One of the toxic materials used was lignasan (ethyl mercury phosphate) a bactericide-fungicide. She found lignasan to be lethal to all species at 0.06 mg/l and 0.0006 was the highest level used not causing drastic inhibition of growth.

Clendenning and North (1960) and North and Clendenning (1958) found that 0.5 mg/l of mercury added as mercuric chloride caused a 50-percent inactivation of photosynthesis of the giant kelp, *Macrocystis pyrifera*, during a 4-day exposure. A concentration of 0.1 mg/l caused a 15-percent decrease in photosynthesis in 1 day and complete inactivation in 4 days. Mercury was more toxic than copper, hexavalent chromium, zinc, nickel, or lead. For phytoplankton, the minimum lethal concentration of mercury salts has been reported to range from 0.9 to 60 mg/l of mercury (Hueper, 1960). The toxic effects of mercury salts are accentuated by the presence of trace amounts of copper (Corner and Sparrow, 1956).

Lead.—Lead is found as a local pollutant of rivers near mines and from the combustion of leaded gasolines. The lead concentration in sea-water is in the order of 0.00003 mg/l. It is found in marine plants at a level of approximately 8.4 mg/l. Residues in marine animals reach a concentration in the range of 0.5 mg/l. It is highest in calcareous tissue.

Wilder (1952) found that lobsters died within 20 days when kept in lead-lined tanks, while in steel-lined and other types of tanks, they survived for 60 days or longer.

North and Clendenning (1958) found that lead was less toxic to the giant kelp, *Macrocystis pyrifera*, than mercury, copper, hexavalent chromium, zinc, or nickel.

Pringle (unpublished data), in studies on the effects of lead on the Eastern oyster, *Crassostrea virginica*, found a 12-week TL_m value of 0.5 mg/l and an 18-week TL_m value of 0.3 mg/l. Concentrations of 0.1 to 0.2 mg/l induced noticeable changes in mantle and gonadal tissue under 12 weeks of exposure.

Nickel.—Nickel is found in sea water in a concentration of about 0.0054 mg/l. Marine plants contain up to 3 mg/l and this may be higher in plankton. Marine animals contain levels in the range of 0.4025 mg/l. Nickel pollution is caused by industrial smoke and other wastes. It is very toxic to most plants but less so to animals. Haydu (unpublished data), in long-term studies with oysters, found that a level of 0.121 mg/l nickel caused considerable mortality.

Zinc.—Zinc is found in sea water in a concentration of 0.01 mg/l. Marine plants may contain up to 150 mg/l of zinc. Marine animals contain zinc in the range of 6 to 1500 mg/l. It is accumulated by some species of coelenterates and mollusks. Speer (1928) reports that very small amounts of zinc are dangerous to oysters.

Clendenning and North (1960) and North and Clendenning (1958) tested the effect of zinc sulfate on the giant kelp, *Macrocystis pyrifera*. Four-day exposure to 1.31 mg/l of zinc showed no appreciable effect on the rate of photosynthesis, but 10 mg/l caused a 50-percent inactivation of kelp.

Other Toxicants

Ammonia-ammonium compounds.—Ammonia is found in the discharge of many industrial wastes. It has been shown that at a level of 1.0 mg/l NH_3, the ability of hemoglobin to combine with oxygen is impaired and fish may suffocate. Evidence indicates that ammonia exerts a considerable toxic effect on all aquatic life within a range of less than 1.0 mg/l to 25 mg/l, depending on the pH and dissolved oxygen level present.

Cyanides.—Hydrocyanic acid or hydrogen cyanide and its salts, the cyanides, are important industrial chemicals. The acid and its salts are extremely poisonous.

Hydrogen cyanide is largely dissociated at pH levels above 8.2 and its toxicity increases with a decrease in pH. The toxic action of cyanides increases rapidly with a rise in temperature.

Fish can recover from short exposure to concentrations of less than 1.0 mg/l (which seems to act as an anaesthetic) when removed to water free of cyanide. They appear to be able to convert cyanide to thiocyanate, an ion that is not inhibitory on the respiratory enzymes. Complex cyanides formed by the reaction of CN with zinc or cadmium are much more toxic. However, the reaction between CN and nickel produces a cyanide complex less toxic than the CN itself at high pH levels.

Sulfides.—Sulfides in water are a result of the natural processes of decomposition, sewage, and industrial wastes such as those from oil refineries, tanneries, pulp and paper mills, textile mills, chemical plants, and gas manufacturing facilities. Most toxicity data available are based on fresh water fish. Concentrations in the range of less than 1.0 mg/l to 25.0 mg/l are lethal in 1 to 3 days.

Fluorides.—Fluorides are present in varying amounts in the earth's crust. They are used as insecticides as well as in water treatment and many other uses. While normally not present in industrial wastes, they may be present in trace or higher concentrations due to spillage. Data in fresh water indicate that they are toxic to fish at concentrations higher than 1.5 mg/l.

Detergents and surfactants.—During the past twenty years, synthetic detergents have replaced a majority of the soap products. Concern about their importance in pollution was heightened by the visible evidence of their foaming in the Nation's waterways. Their toxicity to the aquatic fauna has been very extensively studied, but for the most part it is difficult to establish safe criteria because of the varying conditions of the tests. Relatively little bioassay work on their effects on marine biota has been published, but it is indicated that, unlike soap, detergents are more toxic in highly saline water than they would be in the fresh water areas of tidal estuaries (Eisler, 1965; Eisler and Derrel, 1966).

The 96-hour TL_m values of an ABS detergent to five species of marine fish ranged from 7 to 22 mg/l (Eisler, 1965). Marine kelp were more sensitive and photosynthesis was inhibited 50 percent after 96-hour exposures to about 1.0 mg/l.

Pathogenic organisms.—Oysters, clams, and mussels have a demonstrated ability to accumulate microorganisms, including bacteria and viruses, from their aquatic environments and to serve as a vehicle for the transmission of these microorganisms to their consumers (U.S. DHEW, 1956, 1958, 1962, 1965a; Liu, et al., 1967).

Controls to prevent the transmission of disease through this route have been provided in the United States through the National Shellfish Sanitation Program (NSSP) administered by the Public Health Service, Department of Health, Education, and Welfare on the behalf of the interested State and Federal agencies and the shellfish industry (1965b). This program has established bacteriological quality standards for those waters from which shellfish are to be harvested for direct marketing. These standards, as described in the NSSP Manual of Operation, should be observed for those estuarine areas used for commercial production of shellfish for direct marketing (U.S. DHEW, 1965). The standards that are applied to shellfish harvesting areas have been revised periodically through the mechanism of a shellfish sanitation workshop held at 2 or 3-year intervals. As these standards are revised so should the water quality criteria be modified.

Tar, gas, and coke wastes.—The distillation of coal for the production of gas, coke, and tarry materials used in the manufacture of dyes and various organic chemicals results in a watery waste known as ammoniacal gas liquor, the disposal of which can cause detrimental effects. Ammoniacal gas liquor contains free ammonia, ammonium salts, cyanide, sulfide, thiocyanate, and a variety of aromatic compounds including pyridine, phenols, cresols, xylenols, and aromatic acids. After treatment to remove ammonia, the waste is called "spent gas liquor." Phenol or carboxylic acid is the most abundant of its many phenolic substances, probably the most dangerous to fish.

Phenolic substances are also present in materials used in road surfacing, sheep dips, and many industrial wastes such as those associated with the manufacture of plastics, dyes, and disinfectants. Gas liquor, discharged untreated to a stream, has an extremely high oxygen demand, many times greater than that of sewage. These various groups of organic substances produce a variety of effects on fish varying from intoxication and anaesthesia to paralysis and death.

Pure compounds representative of these groups found in such coal tar wastes have been shown to be toxic in ranges of 2 to 75 mg/l for cresols and 0.1 to 50 mg/l for phenols, for fresh water fish and lower aquatic life.

Petroleum refining and petrochemical wastes.—The volatile components of petroleum consist mainly of aliphatic hydrocarbons. In addition to paraffins and olefins, some petroleums contain relatively high percentages of naphthenes and aromatic hydrocarbons. The less volatile fractions of petroleum are used as fuels, lubricants, and construction materials (asphalt). These substances are somewhat more irritating to the skin and some are carcinogenic, but less so than coal tar products.

Pulp and paper manufacturing wastes.—The types of pulp produced and pulping technology have undergone considerable change in the last 20 years and the trend continues. Modern pulpmills are geared to produce a variety of pulp grades due to the increasing demands for specialty products. The characteristics of the waste waters from these specialty pulp grades can vary considerably. An example of this can be seen in the BOD loadings of the following sulfite grade pulps produced in a west coast mill:

Paper making—130 lb BOD/ADT (air dry ton).
Alpha hardwood—300 lb/ADT.
FAC-SAC—450 lb/ADT.

The major pulping processes include kraft, sulfite, semichemical, and nonchemical such as groundwood. The kraft process accounts for approximately 75 percent of the total pulp production in the United States. The number of mills using the sulfite process are declining, some are being converted to the kraft process.

From the standpoint of water pollution, kraft and sulfite mills are of great significance. The principal problems associated with pulpmill wastes are toxicity, depressed DO's, and slime growths. Clear-cut cases of acute toxicity attributable to pulpmill wastes in modern times seldom exist except when spills or other accidents occur. It is much more common to encounter problems related to slime growths, depressed DO's, and to long-term or chronic effects on the biota.

A substantial portion of pulpmill wastes including the toxic components are very amenable to microbial degradation. In one study, kraft mill wastes were found to be nontoxic to oysters at a dilution of 1:20 when the BOD of the waste was reduced by 80 percent employing biological treatment. In a similar study, the toxicity of kraft wastes to silver salmon was found to diminish proportionally to the degree of BOD reduction above 50 percent, again using biological treatment. The results of a recent study by scientists of the International Pacific Salmon Commission indicate a fairly close relationship between BOD reduction and decrease in the toxicity of kraft wastes. They found no apparent toxicity to salmon when the BOD was reduced by 65 percent. While similar studies have not been made with sulfite liquors, there is some evidence that the toxic components of this waste are also degradable. It is important to recognize that the biological mechanism or degradation involved in secondary treatment is essentially similar to that in receiving waters. Given sufficient time, the process of degradation of the toxic components of pulp wastes also take place in receiving waters.

Because of the great complexity and variability of pulpmill wastes, it is difficult to find a satisfactory expression for concentration. Attempts have been made to relate toxicity to BOD, COD, total solids, PBI (Pearl Benson Index—a measure of the lignin content of pulp wastes), and various reference animals. There is a general relationship with all of these criteria; i.e., the higher the values, the greater the toxicity. Pulpmill dosages or dilutions have been used in bioassays on the basis of applied initial BOD. The response of the test animals has been found to vary considerably to given concentrations of applied BOD even from the wastes of the same mill. This would indicate that the concentration of toxicants in the total biologically amenable fraction is subject to considerable variation. This would not only explain the lack of a good relationship between the toxicity and initial BOD, but it would also explain why, on the other hand, there can coexist a good relationship between BOD reduction and reduction in toxicity. The latter is subject to degradation regardless of the proportions of toxicants and the other to biodegradable substances.

The shortcomings of BOD as an expression of the concentration of toxicity would seem to be equally applicable to the PBI test. This test has been recommended as a measure of SWL (sulfite waste liquor) concentration. It measures the lignins in SWL which constitute an appropriate substance for tracing in receiving waters and for analysis due to their stability and high concentrations. As indicated earlier, critical tests to determine the relationship between BOD reduction and reduction in toxicity have not been conducted with SWL. Nevertheless, there is sufficient evidence to indicate that the toxic components of SWL also reside in the biodegradable fraction and are also degradable. The composition of SWL in receiving waters at different distances from the point of discharge would therefore differ even though similar PBI values may occur. The toxicity of fresh SWL at a PBI concentration of 50 mg/l would be much greater than of biologically stabilized SWL at the same PBI concentration. There is clear indication that further study of SWL toxicity and biodegradation is necessary.

The toxicity of kraft and sulfite wastes to aquatic life is amply reported in the literature. Deleterious effects produced by SWL (generally considered less toxic than kraft wastes) are reported from PBI values as low as 2.0 mg/l for oyster larvae to concentrations greater than 1,000 mg/l for the adult clams *Mya* and *Macoma*. Long-term bioassays with Pacific and Kumamoto oysters, carried out at Oregon State University using calcium-base SWL (10 percent solids), showed no adverse effects at 50 mg/l after 266 days of exposure. Slightly deleterious effects were noted at 100 mg/l, indicating maximum safe limits lie between 50 to 100 mg/l. Continuing field studies at Grays Harbor, Wash., support these findings. In bioassays conducted in salt water by the Washington State Department of Fisheries, salmon exposed for 30 days to concentrations of approximately 500 mg/l of 10-percent SWL showed no apparent ill effects. Herring eggs, on the other hand, were adversely affected at concentrations greater than 96 mg/l.

The apparent tolerance level for salmon in salt water using kraft wastes was found by the above investigation to range from dilutions of 1:16 to 1:90 after 14 to 30 days of exposure. Growth studies conducted at Oregon State University by the National Council for Stream Improvement using raw kraft wastes in fresh water showed no adverse effects to salmonid fishes after 3 to 5 weeks exposure in dilutions of 1:100. English (in press), in his field studies of the English sole in Puget Sound, reports a sustained and thriving fishery in an area affected by SWL. Recent work by the Federal Water Pollution Control Administration (USDI 1967a) in Puget Sound showed damage to oyster larvae and developing English sole eggs at concentrations greater than 10 mg/l of 10-percent SWL. According to this report, oyster growth and market condition is adversely affected and phytoplankton productivity is inhibited at SWL concentrations over 50 mg/l.

Determining the toxicity of complex wastes like oil, refinery petrochemicals, and pulpmill wastes presents a number of problems. For one thing, they contain many known and, perhaps, equally as many unknown toxic substances in small quantities. The toxicological and other physical and chemical characteristics can vary considerably during any given day, in any given plant, due to changes in processes, sources of supplies, and the end product being produced. Considerable variation in effluent characteristics can occur even in a 1-day period. The resulting wastes from these industries contain upwards of several hundreds of compounds representing a number of homologous series of compounds from different organic groups. This complexity is augmented by the treatment of the wastes, as well as by the spectrum of products manufactured from the complex starting material used. The relative ability to react biochemically and to exert an oxygen demand is characteristic of organic materials of such primary significance.

Many groups or series of compounds indicated to be present in such wastes have been shown to be toxic in varying degrees to aquatic life. It is extremely difficult at this time, however, to place a concentration limit or set threshold criteria for such complex systems and hence should be individually bioassayed and their discharge managed accordingly.

Waterfront and boating activities.—Increasing activities by commercial, military, and recreational vessel operators raise the specter of introduction of toxic materials in quantities sufficient to affect marine organisms adversely. This is particularly likely in the case of confined waters of small tidal tributaries, lagoons, embayments, and other marine areas employed as harbors.

Toxic materials are used to prevent activities of boring and fouling marine organisms. Usually, however, every effort is bent in the case of toxic coatings to prevent rapid release of toxic materials into the environment since rapid loss reduces effectiveness of such coatings and increases costs. Some leaching is unavoidable—even necessary. Thus, the presence in confined harbors of many vessels whose bottoms are coated with toxic materials already presents hazards in some places. This would be especially true after spring "fitting out" for small boats.

Boatowners, boat and boatyard operators, fishing and commercial pier and marina operators are not especially noted for the care extended to nearby waters. Commonly, everything that can be is flushed or jettisoned into the water. Purposeful discharges are many—though perhaps decreasing as emphasis on water pollution has increased. Paint leaching, paint spillage, oil and gasoline spillage, detergents, wood preservatives, exhausted containers, metallic objects of all types (zinc, copper, brass, iron, etc.), and other jetsam contribute to contamination from these sources.

Except for confined areas where there are many of these operations such as large shipyards, major military and commercial anchorages, and large and small boat anchorages, it is doubtful that toxicity from these operations is of serious proportions in tidal waters at this point. As with other fouling or contaminating activities of society, however, efforts should be made to keep biological damage from these sources to a minimum. Some discharges are controllable and should fall under the same rules as industrial or community discharges. In the case of large marinas, shipyards, or major anchorages, requirements suggested elsewhere may have to be applied. Future research should include specific attention to this aspect.

Similar comments can be made about waterfront structures and port operations. There is considerable use of toxic materials in preservation of wood, steel, and masonry structures used on marine waterfronts. Discharge of toxic materials, surfactants, petroleum products, other materials and jetsam is common. Similar recommendations can be made for control and research as those for boat, boatyard, and vessel operations.

Disposal of laboratory wastes.—The rapid growth of marine sciences during the past decade is reflected in an ever-increasing number of stations and laboratories engaged in the study of various aspects of oceanography. These institutions are located along the entire coastline of the United States: 28 on the Atlantic, 12 on the Gulf, and 29 on the Pacific. About 2,500 persons (investigators, students, technicians, and laboratory assistants) are employed in these 66 establishments (Hiatt, 1963).

The above number includes institutions operated by Federal and State governments, by universities or privately endowed concerns which receive their main support from the government and national foundations. Other laboratories, hospitals, and research institutions operated by industrial concerns for their specific needs are not included in this total. The laboratories range from small establishments, with less than four investigators, to very large institutions employing or providing research space for 200 to 500 investigators.

The types of research cover various fields of biology, microbiology, experimental physiology, biochemistry, chemistry, biophysics, molecular biology, radiobiology, fishery biology, fishery management, and industrial research. Consequently, the effluents discharged into estuarine and coastal waters vary from ordinary household sewage to mixtures containing an array of organic and inorganic compounds, drugs, and radioactive isotopes. The composition of these effluents cannot be predicted with certainty because the type of research varies greatly from year to year. The laboratory effluent is separated usually from the sea water system, which as a rule has independent plumbing, but is mixed with the domestic sewage and frequently is discharged into natural waters. When many scientific establishments are concentrated in a relatively small area, the situation may become serious. Chlorinated raw sewage entering the harbor a short distance from shore may be caught by a tidal eddy and for several hours circulate close to the sea water intakes of several laboratories before it is carried out by tides.

To maintain desired water quality requirements for aquatic life, it is necessary to separate laboratory effluents from domestic sewage and provide treatment that renders them harmless to aquatic biota. Under no conditions should highly toxic chemical compounds or drugs be permitted to be discharged into natural waters if toxic concentrations of them can be detected by chemical and physical methods.

Many marine laboratories are utilizing exotic and endemic microorganisms, some pathogenic, in research. Extreme caution must be exercised to prevent contamination of water by introduction of biological materials which can harm marine organisms.

Laboratory administrators should be responsible for the periodical examination of the toxicity of the effluent discharged into natural waters by their institutions.

Recommendation: (1) Allowable concentrations of metals, ammonia, cyanides, and sulfides should be determined by the use of 96-hour TL_m values and appropriate application factors. Preferably, the TL_m values should be determined by flow-through bioassays in which environmental factors are maintained at levels under which these materials are most toxic. Tests should utilize the most sensitive life stage of species of ecological or economic importance in the area. Tentatively, it is suggested that application factors should be $1/100$ for pesticides and metals, $1/20$ for ammonia, $1/10$ for cyanide, and $1/10$ for sulfides.

(2) There is evidence that fluorides are accumulative in organisms. It is tentatively suggested that allowable levels should not exceed those for drinking water.

(3) The further dilution of wastes in marine waters suggests that the adoption of criteria established for detergents and surfactants in fresh water also will protect adequately biota in the marine environment.

(4) Bacteriological criteria of estuarine waters utilized for shellfish cultivation and harvesting should conform with the standards as described in the National Shellfish Sanitation Program Manual of Operation. These standards provide that:

(a) Examinations shall be conducted in accordance with the American Public Health Association recommended procedures for the examination of sea water and shellfish.

(b) There shall be no direct discharges of untreated sewage.

(c) Samples of water for bacteriological examination to be collected under those conditions of time and tide which produce maximum concentration of bacteria.

(*d*) The coliform median MPN of the water does not exceed 70/100 ml, and not more than 10 percent of the samples ordinarily exceed an MPN of 230/100 ml for a 5-tube decimal dilution test (or 330/100 ml where the 3-tube decimal dilution test is used) in those portions of the area most probably exposed to fecal contamination during the most unfavorable hydrographic and pollution conditions.

(e) The reliability of nearby waste treatment plants shall be considered in the approval of areas for direct harvesting.

(5) It is also essential to monitor continuously waste from tar, gas, and coke, petroleum refinery, petrochemical, and pulp and paper mill operations. They all produce complex wastes of great variability, not only from facility to facility, but also from day to day. This should be done on an individual basis with bioassays. These tests should be made at frequent intervals to determine TL_m values as described for other wastes. For the more persistant toxicants, an application factor of $1/100$ should be used while for unstable or biodegradable materials an application of $1/20$ is tentatively suggested.

(6) Concentration of other materials with noncumulative toxic effects should not exceed $1/20$ of the 96-hour TL_m value. For toxicants with cumulative effects, the concentrations should not exceed $1/20$ and $1/100$ for the above respective values.

When two or more toxic materials that have additive effects are present at the same time in the receiving water, some reduction in the permissible concentrations as derived from bioassays on individual substances is necessary. The amount of reduction required is a function of both the number of toxic materials present and their concentrations with respect to the derived permissible concentration. An appropriate means of assuring that the combined amounts of the several substances do not exceed a permissible combination for the mixture is through the use of following relationship:

$$\left(\frac{C_a}{L_a}+\frac{C_b}{L_b}\cdots+\frac{C_n}{L_n}\leq 1\right)$$

Where C_a, C_b . . . C_n are the measured concentrations of the several toxic materials in the water and L_a, L_b . . . L_n are the respective permissible concentrations (limits) derived for the materials on an individual basis. Should the sum of the several fractions exceed one, then a local restriction on the concentration of one or more of the substances is necessary.

wildlife

WILDLIFE require water of a quality adequate to maintain their health, as well as optimum production of beneficial biota in their environment. A healthy animal is one that can survive to an average lifespan, display normal behavior and migration patterns, and reproduce successfully. We are fully as concerned with the impact of pollution on the wildlife habitat as we are with the direct or indirect effects on the various species of wildlife. Optimum production of beneficial biota in the multifarious wildlife habitats implies maintenance of natural, balanced ecosystems unaltered by pollution.

Wildlife is defined herein as all species of mammals, birds, reptiles, and amphibians. Because of the dependence of waterfowl on aquatic habitats, their needs form the primary basis for definition of water quality requirements for wildlife. In most instances, water quality satisfactory for waterfowl and their habitat would be satisfactory for most other wildlife species. It is axiomatic that water quality that can be tolerated by, and is productive of, fish and their food organisms is generally adequate for waterfowl and their habitat. Indeed, fish and many of the organisms upon which they feed are also important in the diet of many species of wildlife; e.g., pelicans, loons, mergansers, other ducks, herons, otters, bears, raccoons, snakes, alligators, etc. It is obvious that requirements for survival of fish and aquatic organisms also constitute the same requirements for preservation of the wildlife habitat. Because of the greater sensitivity of fish and their food organisms to pollution, much more intensive research has been required and conducted with those forms than with wildlife.

The water quality requirements stipulated for fish and aquatic organisms generally are acceptable for wildlife in regard to the following environmental factors and materials: dissolved oxygen, temperature, pH, carbon dioxide, alkalinity, hardness, salinity, sulfides, ammonia, nutrients, floating materials, surface active agents, tainting materials, radionuclides, heavy metals, pesticides, and other chemicals. Certain of these factors including DO, pH, alkalinity, salinity, light, settleable solids, oil, and nuisance growths must be considered in their special relations to wildlife and waterfowl and their habitats. These are discussed separately.

Dissolved oxygen

In waterfowl habitats, in addition to DO requirements for the open water, there is need to keep the bottom aerobic for the suppression of botulinus organisms. Botulism, caused by *Clos-*

tridium botulinum, has killed millions of water birds. Jensen and Williams (1964) state "When conditions are favorable—suitable temperature, an organic medium to satisfy food requirements, and an absence of atmospheric oxygen (the organism is a strict anaerobe)—the spores germinate and multiply." Although the exact qualities of the water favoring its production cannot always be categorized, anaerobic conditions in shallow, fringe areas of ponds or reservoirs often are indicted as contributory to botulism outbreaks. Maintenance of adequate water circulation in *all parts* of these shallow reservoirs might deter production of the toxic bacteria. Also, accumulation of organic wastes from mills and other sources should be prevented in aquatic habitats, particularly where botulism has been a problem.

pH

The chapter in *Waterfowl Tomorrow*, by McCallum (1964), entitled "Clean Water, and Enough of It," summarizes many of the water pollution problems of aquatic habitats. McCallum states "Acid mine water has destroyed or seriously damaged the waterfowl value of more than 4,000 miles of streams in the United States. Working as well as abandoned coal mines discharge an estimated 3.5 million tons or more of acid each year into streams, most of them east of the Mississippi River." Martin and Uhler (1939) point to the fact that "acidity may affect the growth of plants by checking the work of nitrifying bacteria and thereby preventing the normal decay of humus, or by increasing the accumulation of carbon dioxide and accompanying toxic organic substances."

In bioassays with aquatic plants, Sincock (1966) found that when the pH of the water in some test vessels dropped to 4.5, redhead-grass (*Potamogeton perfoliatus*), a valuable waterfowl food plant, died within a few days. Similarly, in Back Bay, Va., between August and November, 1963, the aquatic plant production in pounds per acre declined from 164 to 13; this atypical decline was immediately preceded by an atypical decline in pH to 6.5 compared to previous midsummer readings of 7.7 to 8.5.

Generally, the submerged aquatic plants of greatest value as waterfowl foods thrive best in waters with a summer pH range of 7.0 to 9.2.

Alkalinity

Generally, waters with reasonably high bicarbonate alkalinity are more productive of valuable waterfowl food plants than are waters with low bicarbonate alkalinity. Few waters with less than 25 mg/l bicarbonate alkalinity can be classed among the better waterfowl habitats. Many waterfowl habitats productive of valuable waterfowl foods, such as sago pondweed (*Potamogeton pectinatus*), widgeongrass (*Ruppia maritima* and *R. occidentalis*), banana waterlily (*Castalia flava*), wild celery (*Vallisneria americana*) and others, have a bicarbonate alkalinity range of 35 to 200 mg/l.

Definitive, submerged aquatic plant communities develop in waters with different concentrations of bicarbonate alkalinity. It is logical to presume that excessive and prolonged fluctuation in alkalinity would not be conducive to stabilization of any one plant community type. There is not sufficient experimental evidence available to define the effects of various degrees and rates of change in alkalinity on aquatic plant communities. Fluctuations of 50 mg/l probably would contribute to unstable plant communities. Fluctuations of this magnitude are quite possible due to canals connecting watersheds, diversion of irrigation water, flood diversion canals, etc.

Salinity

Salinity may have a twofold effect on wildlife: a direct one affecting the body processes of the species involved and an indirect one altering the environment, making living and species perpetuation difficult or impossible.

Direct Effect of Salinity

A review of the available literature produced very little information on possible effects of salinity upon game mammals. There was a single reference made in which a 0.9-percent solution of sodium chloride was listed as innocuous to mammals (Selye, 1943).

As evidenced by the literature, salinity has a very detrimental effect on all of the domestic species of the order Galliformes (chickens and turkeys). A solution of 0.9-percent sodium chloride used by Barred Rock chickens for drinking purposes was extremely toxic, causing numerous deaths (Krista, et al., 1961). The birds exhibited water retention in the body and marked renal changes. While working with turkey poults, it was found that a 0.5-percent sodium chloride solution was fatal to 50 percent of the individuals tested and in addition that various sodium compounds (sodium citrate, sodium carbonate) in 0.75- percent solutions also were very toxic (Scrivner, 1946). There was a significant drop in egg production by white leghorn chickens that drank a 1.0-percent salt solution and a 0.7-percent salt solution used for drinking water caused a significant mortality in day-old chicks. It is reported that a 0.52-percent salt solution used for drinking water retarded growth in domestic chickens (Rosenberg and Sess, 1954). Using a 0.35-percent salt solution for drinking water increased mortality of baby chicks, however, water containing 0.30, 0.26, and 0.25 percent salt was nontoxic (Doll, et al., 1946).

Correlation of this toxicity to avian game was indicated when a group of ornamental pheasants (order Galliformes) and chickens were salt poisoned; all the pheasants succumbed, but only a few of the chickens (Field and Evans, 1946). Young ducklings were killed or retarded in growth as a result of salt poisoning by solutions equal to those found on the Suisun Marsh, Calif., during the summer months (Suisun Marsh is formed by the combined deltas of several rivers; i.e., Sacramento, San Joaquin, and the Middle River. Griffith, 1963). Salinity maxima during July (1956 to 1960) varied from 0.55 to 1.74 percent; the means varied from 0.07 to 1.26 percent. During 3 of these years the mean salinity level exceeded levels reported as causing mortality in domestic chickens. Adult quail preferred dehydration to drinking water having a salt concentration that would be fatal to juvenile chickens and detrimental to egg production (Bartholemew and MacMillan, 1961).

These conditions must be kept in mind because there is a potential hazard of a sodium compound buildup in the Lower Colorado River area to levels that would be toxic to avian game.

Indirect Effects of Salinity

Indirect effects of salinity on wildlife would generally be restricted to that action imposed upon the vegetative growth along the river. Modification of a segment of the associated vegetation can result in a complete change in the environment. The game animals affected by a modification of submergent and emergent vegetation would be mainly the various species of waterfowl.

Different habitats, of use to a great variety of wildlife, develop under different concentrations of salinity. In coastal areas, where the salinity generally represents various dilutions of sea water, the habitats can be categorized as fresh to slightly brackish (0 to 3.5‰), moderately brackish (3.5 to 13.5‰), and strongly brackish to marine (13.5 to 35.0‰). Valuable submerged aquatic plants occurring in the first category are bushy pondweed, *Najas guadalupensis*, northern naiad, *Najas flexilis*, several pondweeds, *Potamogeton spp.*, wild celery, *Vallisneria americana*, and watershield, *Brasenia schreber*.

In moderately brackish waters, some of the better waterfowl foods are sago pondweed, *Potamogeton pectinatus*, muskgrasses, *Chara spp.*, horned pondweed, *Zanichellia palustris*, and a few pondweeds, *Potamogeton spp.*, that thrive in both fresh waters and moderately brackish waters.

Important food plants for waterfowl in the most saline waters are widgeongrass, *Ruppia maritima*, shoalgrass, *Diplanthera wrighti*, spiny naiad, *Najas marina*, and eelgrass, *Zostera marina*.

Probably the most important consideration, in regard solely to salinity and the plant communities which develop, is the degree of fluctuation. Observations and bioassays by Bourn (1932), Martin and Uhler (1939), Sincock (unpublished data), and others have demonstrated the destructive effects of rapid fluctuations in salinity on aquatic plants. Plasmolysis of the tender leaves and stems, induced by changes in osmotic pressure of the varied water salinities, results in death of the plants.

Based on empirical knowledge, it is believed that salinity fluctuations in a 24-hour period could be 1, 2, and 4‰ in each of the three respective salinity classes without causing harm to most of the aquatic plants.

Emergent marsh plants also have varying tolerances to water salinity; generally, they are not as sensitive to minor changes as are the submerged aquatic plants. Fresh water marshes are normally much more productive of wildlife food plants than strongly saline marshes.

The reaction of vegetation associated with waterfowl marshes to salinity has become an important consideration in the management of those marshes. Salinity of 6‰ and above is detrimental to many prime, submergent waterfowl food plants (Tester, 1963). Controlled salinity levels, however, have become a valuable tool in marsh management. Undesirable marsh plants can be controlled or eliminated and desirable plants encouraged by manipulation of salinity levels (California Department of Fish and Game, 1963). For example, the seeds of cattail (an undesirable plant) will not germinate in a solution having 7 mmhos conductivity while alkali bulrush (desirable plant) will germinate in solutions of up to 9 mmhos conductivity (Kaushik, 1963). Therefore, raising salinity levels to 8 mmhos conductivity would eliminate cattail, but allow alkali bulrush to flourish.

The germination of seeds and the growth of seedlings are critical stages in the plant-salinity relationship; plants become more tolerant to salinity with age. Adult plants of cattail, hard-stem bulrush, and alkali bulrush can withstand saline solutions of 10, 15, and 18 mmhos conductivity, respectively.

There is an increasing amount of cultivation of agricultural crops for waterfowl feeding purposes (barley and Bermuda pasture grass) on waterfowl management areas along the lower Colorado River (Land, personal communication). An increasing level of salinity in the river, if the crops are irrigated with river water, may have a detrimental effect upon this practice. It has been stated that alkali bulrush grows in soil having salinity levels well above the survival range of agricultural crops (Nelson, 1953). Therefore, though natural marsh growth along the lower Colorado River should not be affected by an increase in salinity, artificially developed waterfowl feeding areas on wildlife management areas may be detrimentally affected.

Factors Associated with Increased Salinity

There are three other aspects of water quality that are normally associated with irrigation return water. They are toxic residues, turbidity, and high temperature.

These waters may contain toxic residues of insecticides and herbicides used as a part of agricultural practices, which may affect avian game species (Rudd and Genelly, 1956). Turbidity has a very definite effect on submerged aquatic plants, limiting growth or even eliminating all submergent vegetation. Another characteristic of irrigation return water is high temperature. A rise in temperature causes an amplification of the effects of salinity upon vegetative growth (Ani and Powers, 1938).

Assessment of any of these possible sources of wildlife damage would necessitate thorough examination of existing conditions for correlation to projected conditions.

Light penetration

Algae, turbidity from silts and clays, and color of the water all affect one environmental factor of major importance in the productivity of aquatic wildlife habitat—light penetration of the water. The results of many of man's activities, including agriculture, industry, navigation, channelization, dredging, land modification, and eutrophication from sewage or fertilizers, often reduce light transmission to the degree that aquatic angiosperms of value to wildlife cannot grow.

Bioassays and field studies by Bourn (1932) and Sincock (unpublished data) demonstrated that at least 5 percent of the total incident light at the surface was required for growth of several aquatic plants (as measured while the sun was near its apex, between 10 a.m. and 2 p.m.). Optimum production occurred where 10 to 15 percent of the light reached the bottom. Most aquatic plants will grow in water depths of 6 feet or more if sufficient light is available. For optimum growth in aquatic wildlife habitats the light at the 6-foot depth should be 10 percent of incident light at the surface; tolerable limits would be 5 percent of the light at the surface to the same depth. *In situ* determinations of light penetration, as measured with a subsurface photometer, provide the best indication of suitability for plant growth.

Observations have indicated that prolonged exclusion of adequate light results in the destruction of submerged aquatic plants; the period during which the plants must endure less than 5 percent of the incident light at the surface should probably not exceed 7 consecutive days if they are to survive.

Of course, light penetration and the factors affecting it; e.g., turbidity, color, and algal concentrations, vary in intensity daily, seasonally, and annually. In most areas, the submerged aquatic plants die back in the fall and winter and the quantity of light required becomes less critical as a requirement. In the spring and summer, however, sufficient light is imperative to growth.

Settleable substances

Accumulation of silt deposits is destructive to aquatic plants, not only by the associated turbidity, but by the creation of a soft, semiliquid substratum inadequate for anchoring the roots. Back Bay, Va., and Currituck Sound, N.C., serve as examples of the destructive nature of silt deposition. Approximately 40 square miles of bottom are covered with soft, semiliquid silts up to 5 inches deep; these areas, constituting one-fifth of the total area, produce only 1 percent of the total aquatic plant production.

Oil

Waterbirds, muskrats, otters, and many other wildlife species require water that is free of surface oil. Studies by Hartung (1965) demonstrated that egg laying was inhibited when mallards ingested small quantities of oil. When oil from the plumage was coated on mallard eggs, it reduced hatching from 80 to 21 percent. The full significance of this type of damage to wildlife populations is unknown.

Dramatic losses of waterbirds (ducks, geese, coot, swans, gannets, murres, and others) result from contamination of the plumage by oil from the surface of the water. Once the bird's plumage is soaked with oil, the bird loses its natural insulation to the cold and dies. Many hundreds of thousands of birds have died from oil pollution in some years in North American waters.

Oil that settles to the bottom of aquatic habitats can blanket large areas and destroy the plants and animals of value to waterfowl. Reportedly, some oil sludges on the bottoms of aquatic habitats tend to concentrate pesticides, thus creating a double hazard to waterfowl that would pick up these contaminants in their normal feeding process.

Pesticides

No pesticides should occur in water to the degree that they affect the health, reproduction, and natural growth of wildlife. Although tolerable limits of pesticides for fish and aquatic invertebrates presently serves as the best guideline to limits that might not cause excessive harm to wildlife, we must call attention to the paucity of our knowledge on the significance of biological magnification. Keith (1966) and Hickey, Keith, and Coon (1966) reported 14 μg/l of DDT and its metabolites in lake bottom muds. About 50 times that quantity was reported in amphipods (*Pontoporeia affinis*), 500 times as much in fish and old squaw ducks, and 15,000 times as much in herring gulls that ate the fish. Reproduction of the gulls decreased.

DDT residues in wildlife are cosmopolitan, occurring even in penguins from the Antarctic. Concentration of insecticides in the flesh of edible wild animals poses a potential hazard to man's well being. Recently, the hunting season for pheasants in California was closed for a while because of concern about secondary poisoning to man.

In our infinite ignorance of the dynamics of biological magnification in wildlife habitats, tolerable limits for pesticides in water cannot be realistically established.

Seldom do we observe mass mortality of wildlife from pesticide application, but occasionally isolated examples occur. Sincock (personal communication) observed an aerial spraying operation of 2 pounds of toxaphene and 1 pound of DDT per acre for armyworm control on soybeans in Virginia in September 1960; 2 days later he was called to determine the cause of death of several geese and ducks penned in the area. Dead fish in adjacent canals also confirmed the presumptive diagnosis of death from pesticidal poisoning.

Nuisance and toxic growths

Algae present several problems to wildlife and their habitat. Excessive blooms can reduce light penetration, as already mentioned; *Nostoc spp.* and other colonial algae often attach to higher aquatic plants and virtually weigh them to the bottom, causing their destruction. *Cladophora sp.* growths in Great South Bay, Long Island, have become a major problem as a result of fertilization by sewage effluents and wastes from duck farms. Although problems with sewage disposal occur throughout the Nation, some of the most severe occur in small, coastal resort areas that must accommodate a massive influx of tourists during the warm, summer season, along with the skyrocketing use of boats with toilet facilities.

Sincock, Inglis, and Irby (unpublished data) contacted most agencies concerned with pollution and conservation problems along the Atlantic and Gulf Coast in August 1966. Many examples of sewage pollution were found. One large southern city dumped 15 million gallons of untreated sewage each day into its harbor. Another mid-Atlantic city had major problems with odors caused by the disintegration of sea lettuce (*Ulva lactuca*) that thrived upon sewage effluent in the harbor.

Several of our national wildlife refuges are, unfortunately, downstream from the inflow of treated and untreated sewage. The problems include offensive odors, sterility of the entire aquatic biota, excessive algal blooms that exclude light, and toxic algae. Some algae, e.g., sea lettuce, reportedly taint the flesh of brant and other waterfowl that consume it.

Several of the blue-green algae are toxic. Olson (1964) states, "When a toxic strain becomes predominant in a water bloom, hundreds of birds may die in a few hours. Then any living creature that drinks the water is a potential victim, and shorelines may be strewn with bodies of mammals, land birds, and waterfowl." Gorham (1964), discussing livestock and wildlife poisoning from his notable research on algae poisoning, states "Five species have been most implicated in such poisonings: *Microcystis aeruginosa* (including *Mic. toxica*), *Anabaena flos-aquae* (including *An. lemmermannii*), *Aphanizomenon flos-aquae*, *Gloetrichia echinulata*, and *Coelospaerium kutzingeanum*." In controlled tests, Olson (1964) found that time of death was generally related to the size of the dose. Four teaspoonfuls of an unconcentrated suspension of *Anabaena lemmermanni* killed a great blue heron in 14 minutes. Olson further states "Extensive algae blooms are potentially dangerous to waterfowl, especially where the principal component is *Anabaena flos-aquae* or *Anabaena lemmermanni*, . . . To forestall wildfowl losses, it would be desirable to keep surface waters free of heavy algae growths".

Lead poisoning

The most demonstrative cause of waterfowl mortality from pollution is lead poisoning. Twelve million pounds of lead shot are expended annually over the Nation's best waterfowl habitats. The shot remains there relatively unchanged. Waterfowl frequently ingest these shot and die. Annual mortality is estimated at roughly 1 million birds.

The major ammunition companies and several conservation organizations currently are conducting research to develop a relatively nontoxic shot; this endeavor should be continued until a satisfactory solution is discovered and this annual source of pollution is stopped. A change in shot-type and adjustment of industry to its production and use would seem possible in 4 years.

Disease

An understanding of the ecological relationships of wildlife disease, water pollution, and water quality characteristics is yet to be obtained. Botulism, fowl cholera, and aspergillosis all can affect birds in aquatic habitats. Although certain conditions of temperature, alkalinity, organic matter, and other factors in the environment are suspect as contributing to disease outbreaks no exact parameters can be defined. Offal from poultry houses, dumped directly into estuaries in Maine, was suspected of causing recent wildlife losses from fowl cholera.

Rare and endangered species of wildlife

Finally, it is believed that the preservation of individual wildlife species presents a challenge and obligation to this generation and to those that follow. To meet this challenge environmental requirements for wildlife must be maintained so that no species become extinct because of water pollution.

The bald eagle, the symbol of the United States, has declined drastically in parts of the United States. Studies are underway to determine the cause. Although pesticides are largely suspect, it has been suggested that lead poisoning, due to eating ducks that died from crippling or lead poisoning, might be involved.

Water quality requirements for endangered species of fish and wildlife should receive State and Federal review on all applicable interstate waters and be of the highest quality obtainable.

Recommendation: To preserve suitable waterfowl food plants, salinity fluctuations in a 24-hour period should not exceed 1‰ in fresh to slightly brackish water (0 to 3.5‰); 2‰ in moderately brackish water (3.5 to 13.5‰); and 4‰ in strongly brackish to marine waters (13.5 to 35‰).

For optimum growth of aquatic food plants, at least 10 percent of incident light at the water surface should reach a depth of 6 feet. Light penetration to this depth must not be less than 5 percent of the incident light.

To prevent the destruction of food plants, reductions in light below the 5-percent levels should not prevail for more than 7 days. This is especially important during the local growing season.

The submerged aquatic plants of greatest value as wildfowl foods thrive best in waters with a summer pH range of 7.0 to 9.2.

For the protection of water birds, the habitat should be free of oil. No pesticides should occur in the water at concentrations which adversely affect the health and use of wildlife either directly or through accumulation of these materials which render them unfit for food of other wildlife or for man. Levels satisfactory for aquatic organisms should also be safe for wildlife, but biological magnification must be considered.

Fertilization by the addition of organic wastes, fertilizers, or other materials should be so limited that nuisance growths are not induced.

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appendix

Glossary of Commonly Used Biological and Related Terms in Water and Waste Water Control*

Acclimation—The process of adjusting to a change in an environment.

Adaptation—A change in the structure, form, or habit of an organism resulting from a change in its environment.

Aerobic Organism—An organism that thrives in the presence of oxygen.

Algae (Alga)—Simple plants, many microscopic, containing chlorophyll. Most algae are aquatic and may produce a nuisance when conditions are suitable for prolific growth.

Algicide—A specific chemical highly toxic to algae. Algicides are often applied to water to control nuisance algal blooms.

Algology—The study of algae.

Amphipods—(*see* Scuds).

Anadromous Fishes—Fishes that spend a part of their life in the sea or lakes, but ascend rivers at more or less regular intervals to spawn. Examples are sturgeon, shad, salmon, trout, and striped bass.

Anaerobic Organism—An organism that thrives in the absence of oxygen.

Annelids—Segmented worms, as distinguished from the nonsegmented roundworms and flatworms. Most are marine; however, many live in soil or fresh water. Aquatic forms may establish dense populations in the presence of rich organic deposits. Common examples of segmented worms are earthworms, sludgeworms, and leeches.

Assimilation—The transformation of absorbed nutrients into body substances.

Autotrophic Organism—An organism capable of constructing organic matter from inorganic substances.

Benthic Region—The bottom of a body of water. This region supports the benthos, a type of life that not only lives upon but contributes to the character of the bottom.

Benthos—Aquatic bottom-dwelling organisms. These include: (1) Sessile animals, such as the sponges, barnacles, mussels, oysters, some of the worms, and many attached algae; (2) creeping forms, such as insects, snails, and certain clams; and (3) burrowing forms, which include most clams and worms.

Bioassay—A determination of the concentration of a given material by comparison with a standard preparation; or the determination of the quantity necessary to affect a test animal under stated laboratory conditions.

Biomass—The weight of all life in a specified unit of environment or an expression of the total mass or weight of a given population, both plant and animal.

Biota—All living organiums of a region.

Bivalve—An animal with a hinged two-valve shell; examples are the clam and oyster.

Bloom—A readily visible concentrated growth or aggregation of plankton (plant and animal).

Blue-Green Algae—A group of algae with a blue pigment, in addition to the green chlorophyll. A stench is often associated with the decomposition of dense blooms of blue-green algae in fertile lakes.

Catadromous Fishes—Fishes that feed and grow in fresh water, but return to the sea to spawn. The best known example is the American eel.

Clean Water Association—An association of organisms, usually characterized by many different kinds (species). These associations occur in natural unpolluted environments. Because of competition, predation, etc., however, relatively few individuals represent any particular species.

Coarse or Rough Fish—Those species of fish considered to be of poor fighting quality when taken on tackle and of poor food quality. These fish may be undesirable in a given situation, but at times may be classified differently, depending upon their usefulness. Examples include carp, goldfish, gar, sucker, bowfin, gizzard shad, goldeneye, mooneye, and certain kinds of catfish.

Coelenterate—A group of aquatic animals that have gelatinous bodies, tentacles, and stinging cells. These animals occur in great variety and abundance in the sea and are represented in fresh water by a few types. Examples are hydra, corrals, sea anemones, and jellyfish.

Cold-Blooded Animals (Poikilothermic Animals)—Animals that lack a temperature regulating mechanism that offsets external temperature changes. Their temperature fluctuates to a large degree with that of their environment. Examples are fish, shellfish, and aquatic insects.

Consumers—Organisms that consume solid particles of organic food material. Protozoa are consumers.

Crustacea—Mostly aquatic animals with rigid outer coverings, jointed appendages, and gills. Examples are crayfish, crabs, barnacles, water fleas, and sow bugs.

Daphnia (*see* Water Fleas).

Dermatitis—Any inflammation of the skin. One type may be caused by the penetration beneath the skin of a cercaria found in water; this form of dermatitis is commonly called "swimmers' itch."

Dystrophic Lakes—Brown-water lakes with a very low lime content and a very high humus content. These lakes often lack nutrients.

Ecology—The science of the interrelations between living organisms and their environment.

Emergent Aquatic Plants—Plants that are rooted at the bottom but project above the water surface. Examples are cattails and bulrushes.

Environment—The sum of all external influences and conditions affecting the life and the development of an organism.

Epilimnion—That region of a body of water that extends from the surface to the thermocline and does not have a permanent temperature stratification.

Estuary—Commonly an arm of the sea at the lower end of a river. Estuaries are often enclosed by land except at channel entrance points.

Eulittoral Zone—The shore zone of a body of water between the limits of water-level fluctuation.

Euphotic Zone—The lighted region that extends vertically from the water surface to the level at which photosynthesis fails to occur because of ineffective light penetration.

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* Extracted from: Geckler, J. R., K. M. Mackenthun, and W. M. Ingram. 1963.

Eurytopic Organisms—Organisms with a wide range of tolerance to a particular environmental factor. Examples are sludgeworms and bloodworms.

Eutrophication—The intentional or unintentional enrichment of water.

Eutrophic Waters—Waters with a good supply of nutrients. These waters may support rich organic productions, such as algal blooms.

Facultative Aerobe—An organism that although fundamentally an anaerobe can grow in the presence of free oxygen.

Facultative Anaerobe—An organism that although fundamentally an aerobe can grow in the absence of free oxygen.

Fall Overturn—A physical phenomenon that may take place in a body of water during the early autumn. The sequence of events leading to fall overturn include: (1) Cooling of surface waters, (2) density change in surface waters producing convection currents from top to bottom, (3) circulation of the total water volume by wind action, and (4) vertical temperature equality, 4 C. The overturn results in a uniformity of the physical and chemical properties of the water.

Fauna—The entire animal life of a region.

Flatworms (Platyhelminthes)— Nonsegmented worms, flattened from top to bottom. In all but a few of the flatworms, complete male and female reproductive systems are present in each individual. Most flatworms are found in water, moist earth, or as parasites in plants and animals.

Floating Aquatic Plants—Plants that wholly or in part float on the surface of the water. Examples are water lilies, water shields, and duckweeds.

Flora—The entire plant life of a region.

Fry (Sac Fry)—The stage in the life of a fish between the hatching of the egg and the absorption of the yolk sac. From this stage until they attain a length of 1 inch, the young fish are considered advanced fry.

Fungi (Fungus)—Simple or complex organisms without chlorophyll. The simpler forms are one-celled; the higher forms have branched filaments and complicated life cycles. Examples of fungi are molds, yeasts, and mushrooms.

Fungicide—Substances or a mixture of substances intended to prevent, destroy, or mitigate any fungi.

Game Fish—Those species of fish considerod to possess sporting qualities on fishing tackle. These fish may be classified as undesirable, depending upon their usefulness. Examples of fresh water game fish are salmon, trout, grayling, black bass, muskellunge, walleye, northern pike, and lake trout.

Green Algae—Algae that have pigments similar in color to those of higher green plants. Common forms produce algal mats or floating "moss" in lakes.

Herbicide—Substances or a mixture of substances intended to control or destroy any vegetation.

Herbivore—An organism that feeds on vegetation.

Heterotrophic Organism—Organisms that are dependent on organic matter for food.

Higher Aquatic Plants—Flowering aquatic plants. (These are separately categorized herein as Emergent, Floating, and Submerged Aquatic Plants.)

Holomictic Lakes—Lakes that are completely circulated to the deepest parts at time of winter cooling.

Hypolimnion—The region of a body of water that extends from the thermocline to the bottom of the lake and is removed from surface influence.

Insecticide—Substances or a mixture of substances intended to prevent, destroy, or repel insects.

Invertebrates—Animals without backbones.

LD_{50} (*see* Median Lethal Dose).

Lenitic or Lenitic Environment—Standing water and its various intergrades. Examples of lenitic environments are lakes, ponds, and swamps.

Life Cycle—The series of stages in the form and mode of life of an organism: i.e., the stages between successive recurrences of a certain primary stage such as the spore, fertilized egg, seed, or resting cell.

Limnetic Zone—The open-water region of a lake. This region supports plankton and fish as the principal plants and animals.

Limnology—The study of the physical, chemical, and biological aspects of inland waters.

Littoral Zone—The shoreward region of a body of water.

Lotic Environment—Running waters, such as streams or rivers.

Macro-organisms—Plants, animal, or fungal organisms visible to the unaided eye.

Median Lethal Dose (LD_{50})—The dose lethal to 50 percent of a group of test organisms for a specified period. The dose material may be ingested or injected.

Median Tolerance Limit (TL_m)—The concentration of the tested material in a suitable diluent (experimental water) at which just 50 percent of the test animals are able to survive for a specified period of exposure.

Meromictic Lakes—Lakes in which dissovled substances create a gradient of density differences in depth, preventing complete mixing or circulation of the water.

Microorganism—Any minute organism invisible or barely visible to the unaided eye.

Molluscicide—Substances or a mixture of substances intended to destroy or control snails. Copper is commonly used.

Mollus (Mollusca)—A large animal group including those forms popularly called shellfish (but not including crustaceans). All have a soft unsegmented body protected in most instances by a calcareous shell. Examples are snails, mussels, clams, and oysters.

Moss—Any bryophytic plant characterized by small, leafy, often tufted stems bearing sex organs at the tips.

Motile—Exhibiting or capable of spontaneous movement.

Mycology—The study of fungi.

Nekton—Swimming organisms able to navigate at will.

Nematoda—Unsegmented roundworms or threadworms. Some are free living in soil, fresh water, and salt water; some are found living in plant tissue; others live in animal tissue as parasites.

Neuston—Organisms resting or swimming on the surface film of the water.

Osmole—The standard unit for expressing osmotic pressure. One osmole is the osmotic pressure exerted by a one-molar solution of an ideal solute.

Oceanography—The study of the physical, chemical, geological, and biological aspects of the sea.

Oligotrophic Waters—Waters with a small supply of nutrients; thus, they support little organic production.

Organic Detritus—The particulate remains of disintegrated plants and animals.

Oxygen-Debt—A phenomenon that occurs in an organism when available oxygen is inadequate to supply the respiratory demand. During such a period the metabolic processes result in the accumulation of breakdown products that are not oxidized until sufficient oxygen becomes available.

Parasite—An organism that lives on or in a host organism from which it obtains nourishment at the expense of the latter during all or part of its existence.

Pelagic Zone—The free-water region of a sea. (Pelagic refers to the sea, limnetic refers to bodies of fresh water.)

Periphyton—The association of aquatic organisms attached or clinging to stems and leaves of rooted plants or other surfaces projecting above the bottom.

Photosynthesis—The process by which simple sugars and starches are produced from carbon dioxide and water by living plant cells, with the aid of chlorophyll and in the presence of light.

Phototropism—Movement in response to a light gradient; for example, a movement towards light is positive phototropism.

Phytoplankton—Plant plankton that live unattached in water.

Piscicide—Substances or a mixture of substances intended to destroy or control fish populations.

Plankton (Plankter)—Organisms of relatively small size, mostly microscopic, that have either relatively small powers of locomotion or that drift in that water with waves, currents, and other water motion.

Platyhelminthes (*see* Flatworms).

Poikilothermic Animals (*see* Cold-Blooded Animals).

Pool Zone—The deep-water area of a stream, where the velocity of current is reduced. The reduced velocity provides a favorable habitat for plankton. Silt and other loose materials that settle to the bottom of this zone are favorable for burrowing forms of benthos.

Porifera (*see* Sponges).

Potamology—The study of the physical, chemical, geological, and biological aspects of rivers.

Producers—Organisms, for example, plants, that synthesize their own organic substance from inorganic substances.

Production (Productivity)—A time-rate unit of the total amount or organism grown.

Profundal Zone—The deep and bottom-water area beyond the depth of effective light penetration. All of the lake floor beneath the hypolimnion.

Protozoa—Organisms consisting either of a single cell or of aggregates of cells, each of which performs all the essential functions in life. They are mostly microscopic in size and largely aquatic.

Rapids Zone—The shallow-water area of a stream, where velocity of current is great enough to keep the bottom clear of silt and other loose materials, thus providing a firm bottom. This zone is occupied largely by specialized benthic or periphytic organisms that are firmly attached to or cling to a firm substrate.

Redd—A type of fish-spawning area associated with running water and clean gravel. Fish moving upstream sequentially dig a pocket, deposit and fertilize eggs, and then cover the spawn with gravel from the next upstream pocket. Fishes that utilize this type of spawning area include some trouts, salmons, and minnows.

Red Tide—A visible red-to-orange coloration of an area of the sea caused by the presence of a bloom of certain "armored" flagellates.

Reducers—Organisms that digest food outside the cell wall by means of enzymes secreted for this purpose. Soluble food is then absorbed into the cell and reduced to a mineral condition. Examples are fungi, bacteria, protozoa, and nonpigmented algae.

Rheotropism—Movement in response to the stimulus of a current gradient in water.

Riffle—A section of a stream in which the water is usually shallower and the current of greater velocity than in the connecting pools; a riffle is smaller than a rapid and shallower than a chute.

Rotifers (Rotatoria)—Microscopic aquatic animals, primarily free-living, fresh water forms that occur in a variety of habitats. Approximately 75 percent of the known species occur in the littoral zone of lakes and ponds. The more dense populations are associated with a substance of submerged aquatic vegetation. Most forms ingest fine organic detritus for food, whereas others are predaceous.

Scavenger—An organism that feeds upon decomposing organic matter.

Scuds (Amphipods)—Macroscopic aquatic crustaceans that are laterally compressed. Most are marine and estuarine. Dense populations are associated with aquatic vegetation. Great numbers are consumed by fish.

Secchi Disc—A device used to measure visibility depths in water. The upper surface of a circular metal plate, 20 centimeters in diameter, is divided into four quadrants and so painted that two quadrants directly opposite each other are black and the intervening ones white. When suspended to various depths of water by means of a graduated line, its point of disappearance indicates the limit of visibility.

Seiche—A form of perodic current system, described as a standing wave, in which some stratum of the water in a basin oscillates about one or more nodes.

Sessile Organisms—Organisms that sit directly on a base without support, attached or merely resting unattached on a substrate.

Shellfish Poison (Mussel Poison)—A poison present in shellfish that have fed upon certain small marine phytoplankters in which the toxic principles exist. The shellfish concentrates the poison without harmful effects to itself, but man is poisoned through consumption of the toxic flesh.

Species (Both Singular and Plural)—A natural population or group of populations that transmit specific characteristics from parent to offspring. They are reproductively isolated from other populations with which they might breed. Populations usually exhibit a loss of fertility when hybridizing.

Sphaerotilus—A slime-producing, nonmotile, sheathed, filamentous, attached bacterium. Great masses are often broken from their "holdfasts" by currents and are carried floating downstream in gelatinous flocks.

Sponges (Porifera)—One of the sessile animals that fasten to piers, pilings, shells, rocks, etc. Most live in the sea.

Spore—The reproductive cell of a protozoan, fungus, alga, or bryophyte. In bacteria, spores are specialized resting cells.

Spring Overturn—A physical phenomenon that may take place in a body of water during the early spring. The sequence of events leading to spring overturn include: (1) Melting of ice cover, (2) warming of surface waters, (3) density change in surface waters producing convection currents from top to bottom, (4) circulation of the total water volume by wind action, and (5) vertical temperature equality, 4 C. The overturn results in a uniformity of the physical and chemical properties of the water.

Standing Crop—The biota present in an environment on a selected date.

Stenotopic Organisms—Organisms with a narrow range of tolerance for a particular environmental factor. Examples are trout, stonefly nymphs, etc.

Sublittoral Zone—The part of the shore from the lowest water level to the lower boundary of plant growth.

Submerged Aquatic Plant—A plant that is continuously submerged beneath the surface of the water. Examples are the pondweed and coontail.

Swimbladder—An internal, membranous, gas-filled organ of many fishes. It may function as a hydrostatic or sense organ, or as part of the respiratory system.

Swimmers' Itch—A rash produced on bathers by a parasitic flatworm in the cercarial stage of its life cycle. The organism is killed by the human body as soon as it penetrates the skin; however, the rash may persist for a period of about 2 weeks.

Symbiosis—Two organisms of different species living together, one or both of which may benefit and neither is harmed.

Systematics—The science of organism classification.

Thermocline—That layer in a body of water where the temperature difference is greatest per unit depth. It is the layer in which the drop in temperature equals or exceeds 1 C (1.8 F) per meter (39.37 inches).

TL_m (*see* Median Tolerance Limit).

Tolerant Association—An association of organisms capable of withstanding adverse conditions within the habitat. It is usually characterized by a reduction in species (from a clean water association) and an increase in individuals representing a particular species.

Trophogenic Region—The superficial layer of a lake in which organic production from mineral substances takes place on the basis of light energy.

Tropholytic Region—The deep layer of a lake, where organic dissimilation predominates because of light deficiency.

Vertebrate—Animals with backbones.

Warm and Cold-Water Fish—Warm-water fish include black bass, sunfish, catfish, gar, and others; whereas cold-water fish include salmon and trout, whitefish, miller's thumb, and blackfish. The temperature factor determining distribution is set by adaptation of the eggs to warm or cold water.

Waterfleas (Daphnia)—Mostly microscopic swimming crustaceans, often forming a major portion of the zooplankton population. The second antennae are very large and are used for swimming.

Zooglea—Bacteria embedded in a jellylike matrix formed as the result of metabolic activities.

Zooplankton—Protozoa and other animal micoorganisms living unattached in water. These include small crustacea, such as daphnia and cyclops.

Section IV
agricultural uses

introduction

AMERICAN AGRICULTURE is both a modern industry and a way of life. Not only does water quality affect the safety and value of its products, but also the health and welfare of farmers and their families. Farmers do not usually have access to the large, well-controlled water supply and waste disposal systems of the great municipalities.

The Subcommittee on Water Quality for Agricultural Uses is concerned with water used on individual farmsteads, for livestock, and for irrigation of crops.

For farmstead waters, particular attention is given to the use of water by the human farm population for drinking, food preparation, bathing, and laundry. Other important uses include washing and hydrocooling of fruits and vegetables in preparation for sale. Particularly critical is the use of water in the production of market milk where clean, bacteriologically safe water is mandatory. In addition, the current time lag between milk production on the farm and use in the home requires the control of psychrophiles which adversely affect milk quality.

The purity of water consumed by livestock has far-reaching implications; polluted water can cause death or disease of livestock and contaminate animal products. Many pollutants are important to the livestock industry. Some understanding of the tolerance level of these in water is important even though animals also inevitably acquire organisms and contaminants from soils or feeding and watering locations. A dependable source of livestock water of good quality is necessary for the profitable production of animals.

Irrigation is the largest, single-purpose beneficial consumptive use of water in agriculture. Water quality criteria for irrigation become more critical as fuller use is made of both available water and irrigable land. Early irrigation developments were largely on streams where only a small part of the annual flow was used. Such streams contained mainly dissolved solids resulting from the normal leaching and weathering processes. Additional uses concentrated the dissolved solids and introduced other chemical and microbiological pollutants that have become potentially hazardous to crops, livestock, and to man.

Sources of water for agriculture

Other than from precipitation, about three-fourths of the water used in agriculture comes from surface supplies and one-fourth from wells and springs.

Man has been able to make better use of the water by constructing dams, reservoirs, and distribution systems. During the period of greatest need for irrigation and livestock, streamflows are often minimal or even nonexistent. The highly productive irrigated areas of the West have water available because of the very large investment in dams, reservoirs, and water channels.

Another large segment of land is irrigated by pumping water from the ground. The total usable underground water supply has been estimated to be equivalent to 10-year's total rainfall or 35-year runoff (172). Underground waters supply more than 20 billion gallons of water a day for irrigation. The States of California, Arizona, Texas, and New

Mexico alone pump about 14 billion gallons a day for this purpose. Pumping of ground water for supplemental irrigation in the more humid portion of the country has increased greatly in recent years.

Most of the water for individual farmstead use comes from wells. Water from deep wells is more apt to be free from pathogenic organisms than that from springs, shallow wells, and surface sources. Because on-farm treatment may be difficult, deep-well water is ordinarily desirable for individual farmsteads unless dissolved solids are excessive.

A dependable source of livestock water of good quality is necessary for the profitable production of animals.

Problems of agricultural water quality

Because the factories of agriculture are living things, water quality affects not only the end product, but also the efficiency of the production machinery. Livestock, ill because of waterborne disease or excess minerals, and irrigated crops suffering from high salinity of irrigation water are inefficient tools of production.

Agriculture, like any other industry or activity of man, must deal with the quality-lowering impact of *all* man's activities on water. Excessive quantities of silt from agricultural activities, road construction, and urban development plague many of our streams. Pollution from sewage, domestic and industrial, continues to add each year to the water quality problems of the farmer and urban dweller. Upstream irrigation, reservoir evaporation, and lowering or recycling of ground water impose increasingly difficult problems for downstream irrigators because of increased salt concentrations.

Effects of water quality deterioration or the impact of low-quality supplies on agriculture are commonly insidious rather than dramatic. Even relatively small-scale changes may result in large economic consequences because of the sheer size of the activity involved.

Excess salinity has been the instrument of destruction of profitable irrigation from the earliest history of man. Besides the common ions, trace elements in small concentrations, such as boron, may be extremely harmful; and in many areas of the world, pollution of water supplies by untreated or inadequately treated sewage in irrigation results in widespread diffusion of enteric diseases.

While a great deal is known about the inhibiting effects of salinity on plant growth, only very preliminary assessments have been made of the economic consequences in terms of the cost of reducing salinity. Thorne and Peterson (*166*) estimate that approximately 1.35 billion acre feet of river flow in the United States each year carries to the sea between 250 and 330 million tons of salt. This reflects a continuing geological process, which, in total, man may not have changed greatly. But in many places man's activities have made local changes of great importance in the vast process. For example, the total flow of salt down the Colorado River system may not be much greater than it was 100 years ago, but the amount of water transporting the salt has decreased appreciably, thus raising the salt concentration.

Besides direct pollution, management of water resources may result in indirect environmental consequences. Improper irrigation practices may provide favorable environments for vectors of disease, such as mosquitoes for malaria or encephalitis, or snails in schistosomiasis (fortunately, the latter is not prevalent in the United States at the present time). Other aspects of irrigation water resource management include control of weed seeds and insect pests.

Very little attention has been given to the optimum quality of drinking water for farm animals. While the standards of quality for human consumption may not be justified here, this could be a desirable goal because such waters often also serve other uses on the farmstead. There are certain contaminants which may be hazardous to livestock. The danger of direct infection to livestock through the consumption of water contaminated with pathogenic agents is definite and deserves attention.

Private farm systems provide water for drinking purposes, food preparation, laundry, bathing, and preparation of products for marketing. Many farms rely on springs or shallow wells for their water supplies and such supplies may be contaminated. Both the farmer and consuming public benefit from the use of good quality water.

Dairy farming requires large quantities of water for cooling and for washing milk-handling equipment. This must be of drinking water quality even though other uses may not require this degree of purity.

The multiple uses of water in agriculture require that streams and other irrigation supplies be of such quality that potable water can be produced economically on the farm and without serious fluctuations in quality. Furthermore, raw water supplies should be satisfactory usually without treatment, for irrigation of vegetable and fruit crops. The frequency and accuracy of monitoring farm water supply sources should depend in part on the contaminating agents and the probability of peak loading of contaminants in the raw water source. Wherever practical, comments on monitoring needs are included along with the appropriate recommendations for criteria in this report.

Monitoring water quality

Historical water quality data should be reviewed when considering the type, location, and frequency of sampling. If such data are not available, a systematic sampling program to provide background information may be necessary. Continuing water quality data are necessary to evaluate changes which may occur with time. By Executive Order [Bureau of the Budget Circular A–67 (1964)], the Department of the Interior was given responsibility to coordinate collection of both water quality and quantity data and to design and operate a national network for these purposes.

Most hydrological, climatic, and quality variables can be obtained and recorded or transmitted in real-time at both remote and nearby locations using sensors, transducers, and telemetering devices available or under development. Improved sensors, however, are needed for most variables, and continued improvement of entire monitoring systems is desirable.

In interpreting water quality characteristics, consideration should be given to the procedures used in measuring them. This report, therefore, contains references to accepted chemical and biological analytical procedures. One should recognize that these will be continually changed and improved. As new methods are introduced, results should be correlated with those obtained by previously accepted methods.

Scope and objectives of the report

This report gives consideration to water quality criteria of concern to agricultural users. The objectives are to describe limits of use for agricultural purposes. Wherever possible, criteria are expressed as quantitative ranges. Some of these are necessarily broad because of lack of information or of wide flexibility in specific uses; others which may be better understood or more critical, are narrow. Where quantitative estimates are presently impossible, general criteria characteristics are described. In suggesting values for criteria, consideration has been given to both health and economic factors affecting the farmer, food processors, and the ultimate consumers.

summary
and key criteria

Farmstead water supplies

In view of the wide variety of sources used for farmstead water supplies and uncontrolled influences of geographic location and climatic conditions, no single set of values can realistically be established as criteria for farmstead supplies and accordingly most of the values are given in the form of acceptable ranges at point of use. In developing the criteria summarized in table IV–1, considerable reliance has been placed on the U.S. Public Health Service Drinking Water Standards. Water which meets these standards is generally safe and acceptable to the user. Farmstead water supply includes water to be used for all household purposes, washing of raw agricultural commodities, and for milk sanitation. Specific requirements above those for general farmstead use are indicated also. *This summary should be used only in conjunction with the text of this report and appropriate references.* See table IV–1, below.

Livestock water supplies

Available literature on various substances which occur as contaminants of drinking water for livestock has been reviewed. Such contaminants include inorganic elements and their salts, organic wastes and mill effluents, pathogens and parasitic organisms, herbicide and pesticide residues, and radionuclides. Important and significant variables, including nature and intake of dietary dry matter, species, age and productivity of animals, and interrelationships among the contaminating ingredients, make establishment of a single set of water purity values for livestock unfeasible. The relationship of water intake to total dietary intake by livestock is of particular significance. For example, much lower levels of a toxic contaminant should be set for water if the dry feed to be ingested is unavoidably high in the same substance. In general, the risk of toxicity is less from water than from feed sources.

Employment of biological indicators, such as fish, in livestock water supplies is proposed as a means of monitoring their safety from the standpoint of chemical toxicity. Fish do not, however, normally indicate presence of pathogenic organisms with sufficient sensitivity to protect livestock from these contaminants.

Animal pathogens may occasionally enter into a water cycle and management of water resources can materially influence distribution of some diseases. The involvement of the water supply in such cases should be supported by epidemiological studies in addition to presumptive or definitive isolation from the water environment. Danger from certain microbiological pathogens may be increased in situations where water supplies are alkaline.

In some instances, water quality standards are set in conformity with accepted residual levels in marketable animal tissues or products rather than in relation to any demonstrable toxic effect upon the animal themselves.

Irrigation water supplies

Variations and interactions of soils, plants, water, and climate preclude the establishment of a single set of criteria to evaluate all water quality characteristics for irrigation purposes. It is the intent of this report to list tentative criteria where possible and to suggest guidelines where specific criteria cannot be defined. These recommendations are subject to revision as more knowledge accumulates.

The following summary of criteria should be used in conjunction with references to the text of the report as noted.

Salinity

ARID AND SEMIARID REGIONS

Table IV–3 of recommended criteria for salinity or total dissolved solids (TDS) assumes that related factors set forth in this report are taken into consideration. This includes good irrigation practices and soil and plant variables (pp. 167–171).

HUMID REGIONS

Where irrigation is practical in humid areas, it is unlikely that any great accumulations of salt will occur over a period of time. For this reason, criteria suggested above for arid regions may be significantly increased for humid regions. More appropriate criteria are indicated in pages 173–174.

SAR and Sodium

Water having sodium adsorption ratio (SAR) values between 8 and 18 may have an adverse effect on the permeability of soils containing an appreciable proportion of clay because its use causes undesirable amounts of sodium to be adsorbed. Where used on sensitive crops, SAR val-

TABLE IV–1. Key Water Quality Criteria for Farmstead Uses.

Characteristic	Recommendations (at point of use)		Page
	General farmstead uses	Additional special-use requirements	
Taste and odor	Substantially free		124
Color	do		124
pH	6.0 to 8.5	6.8 to 8.5 dairy sanitation	124
Total dissolved inorganic solids	500 mg/l (under certain circumstances, higher levels are acceptable).		124
Dissolved organic compounds	No recommendations for total organics. The concentration of persistent chlorinated organic pesticides should not exceed the following: Compound μg/l Endrin 1 Aldrin 17 Dieldrin 17 Lindane 56 Toxaphene 5 Heptachlor 18 H. epoxide 18 DDT 42 Chlordane 3 Methoxychlor 35		124
Turbidity	Substantially free		125
Hazardous trace elements	Levels in excess of those shown are grounds for rejection of a supply: Substances mg/l Arsenic 0.05 Barium 1.00 Cadmium 0.01 Chromium 0.05 Cyanides 0.2 Lead 0.05 Selenium 0.01 Silver 0.05		125
Other trace elements	Levels shown below should not be exceeded if alternate sources are available: Substances mg/l Manganese 0.05 Iron 0.3 Copper 1.0 Zinc 5.0 Fluoride 0.7–1.2 Nitrate 45.0	In dairy sanitation, water should contain <20 mg/l potassium and <0.1 mg/l iron and copper.	125
Radionuclides	pc/l Strontium-90 10 Radium-226 3 In absence of above radionuclides, 1,000 pc/l gross β activity.		125 125
Nonpathogenic microorganisms	To conform to USPHS drinking water standards.	For dairy sanitation, water should not contain more than 20 organisms per ml and contain not more than 5 lypolytic and/or proteolytic organisms per ml.	125

ues above 4 may be detrimental because of sodium phytoxicity (pp. 155, 164). Water low in salt but high in bicarbonate content may present a permeability hazard even with low SAR values (pp. 170–171).

TABLE IV–2. Key Water Quality Criteria for Livestock Use

Characteristic	Recommendations
Total dissolved solids (TDS)	<10,000 mg/l, depending upon animal species and ionic composition of the water.
Hazardous trace elements:	
Arsenic	<0.05 mg/l
Cadmium	≤0.01 mg/l
Chromium	<0.05 mg/l
Fluorine	<2.40 mg/l
Lead	<0.05 mg/l
Selenium	<0.01 mg/l
Organic substances:	
Algae (water bloom)	Avoid abnormally heavy growth of blue-green algae.
Parasites and pathogens.	Conform to epidemiological evidence.
Dissolved organic compounds.	Biological accumulation from environmental sources, including water, shall not exceed established, legal limits in livestock products.
Radionuclides	Conform to recommendations for farmstead water supplies.

TABLE IV–3. Suggested Guidelines for Salinity in Irrigation Water

Crop response	TDS mg/l	EC[1] mmhos/cm
Water for which no detrimental effects will usually be noticed	<500	<0.75
Water which can have detrimental effects on sensitive crops	500–1,000	0.75–1.50
Water that may have adverse effects on many crops and requiring careful management practices	1,000–2,000	1.50–3.00
Water that can be used for salt-tolerant plants on permeable soils with careful management practices	2,000–5,000	3.00–7.50

[1] Electrical conductivity.

Chlorides

Although not phytoxic to most crops, some chloride phytotoxicity has been found for some fruit crops. No limit has been established for chloride-tolerant crops because detrimental effects from salinity *per se* ordinarily deter crop growth first. For chloride-sensitive crops, chloride content in the soil solution may range from 10 to 50 me/l with permissible levels in irrigation water ranging from 1 to 20 me/l (*16*). More restrictive criteria should be considered where sprinkler irrigation is used (pp. 155–156).

Trace Elements

Toxic limits which would be generally applicable to all soils and all crops are not easily defined. Research literature is inadequate to permit even well-defined guidelines. The limits suggested in table IV–15 are tentative and are designed only to serve as guides for well-drained soils (p. 152).

Radionuclides

There are many considerations involved regarding radioactivity in irrigation water (pp. 163–164). One hazard is the potential accumulation of a radionuclide in a soil reaching levels in excess of that applied in the irrigation water. On the basis of existing knowledge, USPHS Drinking Water Standards (*175*) is the best guide; the standards are: Strontium-90, 10 pc/l; radium-226, 3 pc/l. In the absence of these radionuclides, 1,000 pc/l gross beta activity.

Microorganisms

It is impractical to monitor irrigation water for the numerous pathogenic organisms which may be present (pp. 160–163). For this reason, the following guidelines for coliform limitations are suggested for interim use subject to research confirmation. These are especially applicable where the tops or roots of the irrigated crop are to be consumed directly by man or livestock. The monthly arithmetic average density of the coliform group of bacteria shall not exceed 5,000 per 100 milliliters and the monthly arithmetic average density of fecal coliforms shall not exceed 1,000 per 100 milliliters. Both of these limits shall be an average of at least two consecutive samples examined per month during the irrigation season and any one sample examined in any 1 month shall not exceed a coliform group density of more than 20,000 per 100 milliliters, or a fecal coliform density of more than 4,000 per 100 milliliters.

For the control of plant pathogens, guidelines for irrigation water are best framed in terms of preventive measures rather than by assay procedures.

ph

Acidity or alkalinity as such in irrigation water is seldom directly detrimental to crop growth. Normally, water with pH values of 4.5 to 9.0 should not present any insurmountable problems, but a range of 5.5 to 8.5 would be more desirable (p. 155).

Temperature

Excessively high or low temperatures in irrigation water may affect crop growth and yields (pp. 157, 160). A desirable range of water temperatures is from 55 to 85 F.

Suspended Solids

Sediment and suspended solids may be detrimental in irrigation water because of their effect on irrigation structures and equipment and on the soil to which the water is applied. No guidelines are available to establish standards for either particle size or quantity. (pp. 163, 175)

Pesticides

On the basis of the limited information available, levels of herbicides at which crop injury has been observed are shown in Table IV–4. There is little evidence to indicate that other pesticide contamination of irrigation water would be detrimental to plant growth or accumulate in or on edible plants in toxic concentrations under normal use (pp. 156–157).

Biochemical Oxygen Demand (BOD) and Dissolved Oxygen

Insufficient information is available to suggest guidelines or to indicate that low BOD values or dissolved oxygen content of an irrigation water as such will have a deleterious effect on plant growth or well-drained soils.

TABLE IV–4. Levels of Herbicides in Irrigation Water at Which Crop Injury Has Been Observed [1]

Herbicide	Crop injury threshold in irrigation water mg/l
Acrolein	**Flood or furrow:** beans-60, corn-60, cotton-80, soybeans-20, sugar beets-60. **Sprinkler:** corn-60, soybeans-15, sugar beets-15.
Aromatic solvents (xylene).	Alfalfa->1,600, beans-1,200, carrots-1,600, corn-3,000, cotton-1,600, grain sorghum->800, oats-2,400, potatoes-1,300, wheat-1,200.
Copper sulfate	Apparently, above concentrations used for weed control.
Amitrole-T	Beets (rutabaga)->3.5, corn->3.5.
Dalapon	Beets->7.0, corn-<0.35.
Diquat	Beans-5.0, corn-125.0.
Endothall Na and K salts.	Corn-25, field beans-<1.0, alfalfa->10.0.
Dimethylamines	Corn->25, soybeans->25, sugar beets-25.
2,4-D	Field beans->3.5<10, grapes-0.7–1.5, sugar beets-3.5.
Dichlobenil	Alfalfa-10, corn->10, soybeans-1.0, sugar beets-1.0–10.
Fenac	Alfalfa-1.0, corn-10, soybeans-0.1, sugar beets-0.1–10.
Picloram	Corn->10, field beans-0.1, sugar beets-<1.0.

[1] Data submitted by crops research division, ARS, USDA (unpublished).

NOTE.—Where the symbol ">" is used, the concentrations in water cause no injury. Data are for furrow irrigation unless otherwise specified.

farmstead water supplies

Scope of taskforce considerations

The purpose of this part is to give consideration to water quality criteria that will be of concern in the use of water by the human farm population for their own needs and for all other purposes associated with the operation of a farm excluding use for livestock production and the irrigation of crops. Specifically included will be consideration of quality criteria for water to be used by humans for drinking, food preparation, laundry, and bathing. Consideration will also be given to its use for the washing and hydrocooling of fruits, vegetables, milk, and other animal products in preparation for sale either on the fresh market or to food processors.

Water for Use by the Human Farm Population: An essential requirement for health and comfortable living in rural areas is that every farm have a dependable water supply for domestic use that is palatable, convenient, safe, and of adequate quantity. The ability of the individual farm operator to treat water is limited to simple disinfection, filtration, and softening. Accordingly, the quality of the raw supply and that of the finished water should be the same, unless otherwise indicated.

Farm water supplies can be of ground or surface origin. Ground sources are generally regarded as providing a more dependable supply and as being less variable in composition than surface water. However, it should be recognized that all supplies are subject to pollution and care must be exercised in both the installation and maintenance of water systems.

In general terms, raw waters should be free of impurities which are offensive to sight, smell, and taste. They should be free of any significant concentrations of toxic substances. They should be free also of bacteria or other living forms which cannot be controlled or eliminated by simple processing techniques such as chlorination. The water should be relatively free of radioactive substances since all forms of exposure to radioactivity are considered detrimental to man.

In the development of specific quality characteristics, much reliance has been placed on the Drinking Water Standards developed by the U.S. Public Health Service (USPHS) for water and water supply systems (*175*) used by interstate carriers and others subject to Federal quarantine regulations. Over the years these standards have been found to be reasonable in terms of the possibility of compliance and acceptability of such water for domestic use. The absence of specific references for the quality criteria listed in this report indicates that the values have been taken from the 1962 revision of the USPHS Drinking Water Standards.

Water for Washing and Hydrocooling Raw Farm Products: Advances in agricultural technology relating to the production and handling of farm products has brought about changes in water requirements. An increasing number of large growers are preparing raw fruits and vegetables for direct shipment to the market. Many root crops and some fruits and vegetables are washed before they leave the farm. Changes in fruit production associated with mechanical harvesting and bulk handling and emphasis on quality have made hydrocooling of fruits a common farm practice. To gain greater consumer acceptance of fresh fruits and vegetables, as well as to minimize problems in the processing of fruits and vegetables, washing and hydrocooling of certain crops on the farm is expected to increase in the future.

Although the use of water for hydrocooling and washing has increased, its use in the slaughtering and preparation of livestock for marketing has decreased. The slaughter of animals for home use and commercial marketing has largely been taken over by firms specializing in this operation. Water use in the preparation of poultry products, meat and eggs, for market is also of little importance in the present farm system since this operation has largely been taken over by poultry and egg processing firms.

Water used in the washing or hydrocooling of farm products destined for human consumption on the farm, for sale on the fresh market, or for delivery to a processing plant for canning, freezing, or other type of preparation prior to marketing, should meet drinking water standards.

Water for Use in Washing Milk Handling Equipment and Cooling Dairy Products: To maintain and improve the quality of milk, farmers must produce a premium product. The quality of water used to clean milk utensils may greatly affect the quality of milk. Since modern methods for bulk handling milk on farms require large volumes of water and provide many opportunities for chance contamination of milk, water must be safe and not injurious to milk quality.

Steadily increasing demand for water in the rural areas due to intensified production of livestock, milk, and agricultural crops has required many farm operators to develop additional sources of water. Generally, these secondary sources are of inferior quality and must be treated before use in milk-handling equipment.

The grade A Pasteurized Milk Ordinance of the USPHS (*176*) is accepted as the basic sanitation standard for an ever-increasing portion of our raw milk supply. By December 1964, the Milk Ordinance (1953 edition) was the basis of the milk sanitation laws or regulations of 37 States. The 1965 ordinance has been accepted by the Interstate Milk Shippers Conference as its basic sanitation standard. Additional States are accepting these requirements as the basic standard for the development of local inspection regulations and for reciprocal inspection agreements. Milk supplies for the Interstate Milk Carrier program and for many Government installations and programs must comply with requirements of the 1965 ordinance. The sanitation requirements for grade A raw milk for pasteurization describe farm water supplies as a major compliance item. Item 8r in section 7 of the 1965 ordinance defines acceptable water supplies under this USPHS standard. It states that "water for milkhouse and milking operations shall be from a supply properly located, protected, and operated, and shall be easily accessible, adequate, and of a safe sanitary quality." Specific instructions for location of water sources, construction of individual farm and milk plant water systems, and disinfection of these supplies are described in appendix D of the 1965 ordinance. The bacteriological requirements for private supplies and recirculated cooling water are listed in appendix G of the ordinance.

While contributing greatly to the development of a safe, sanitary raw milk supply in this country, the water quality standards described in the 1965 ordinance (as well as in previous USPHS model milk codes) are inadequate. Farm water supplies may meet these standards, yet have a detrimental effect on the quality of our modern milk supply.

Traditional concepts of "potability" and "softness" no longer suffice in this era of mechanized milk-handling systems. Lengthy storage of raw milk prior to pasteurization is common in today's marketing operation. The breakdown of normal milk constituents by organisms able to grow at refrigeration temperatures produces quality changes not tolerated in fluid milk or manufactured dairy products. Since many of these low-temperature-tolerant species of microorganisms are common soil and water contaminants, water quality standards must be developed for farms producing milk to prohibit the presence of those species which can cause the breakdown of milk constituents.

The following characteristics are considered essential in a water supply to produce a milk supply able to meet the demands of a modern marketing system.

1. **Sufficient quantity.**—Enough water must be

available every day throughout the year. Failure of the supply, such as during a drought or freezing weather, has serious consequences in milkhouse sanitation. Sanitary care of milk-handling equipment is an everyday must and when water is scarce, sanitation suffers.

2. **Clear, colorless, good taste, relatively soft.**—Soft water requires less detergent and gives better cleaning. Dirty water results in dirty utensils. Milk is susceptible to off flavors; poor tasting water does not help.

3. **Free from harmful bacteria, yeast, and molds.**—Unsafe water may cause disease. Some bacteria cause rancid flavors in milk while others can cause bitter, fruity, and/or other unpleasant flavors. Yeasts and molds also contribute to flavor defects of milk products.

4. **Noncorrosive water.**—Corrosion shortens the life of piping and water heaters. Copper and iron dissolved from piping by acid water may cause oxidized flavors in milk products.

5. **Nonscale-forming water.**—Scale may clog pipes, faucets, boilers, and water heaters (*111*).

General problem areas

Limitations of On-Farm Treatment: The raw water supply available to farmers must be of such quality that it can be used in the raw state or be made acceptable for farmstead use with minimum treatment such as disinfection, filtration, and/or softening. Economic considerations alone will prohibit use of raw supplies that require extensive treatment to make them suitable for farmstead uses.

Many surface waters have turbidities in excess of what can be used effectively in home or farm operations. The coagulation, settling, and filtration systems used in municipal water plants are impractical for small-scale use. Pressure sand filters or diatomaceous earth filters are not recommended for farm use when turbidities exceed 20 units and are not effective at this level if the supply has excessive bacteria or organic materials present. Small in-line filters with porous rigid media or composition disc filters are used successfully for small systems but are not successful if high capacity is desired or if turbidities exceed 5 to 10 units (*89*).

Control of water hardness is desirable for domestic uses and is essential for proper sanitary control of milk contact surfaces. However, except for supplies containing in excess of 100 to 150 mg/l total hardness, cleaning compounds can be formulated which provide adequate softening. Such water may produce waterstone in heaters or milk cooling tanks when used for ice-bank cooling or for water-cooled compressors.

For farm supplies exceeding 100 mg/l total hardness, control can be effective using cation exchange processes. When properly operated, ion exchange systems are quite inexpensive and generally satisfactory. However, unless the equipment is properly maintained and operated the ion exchange capacity of the system will be depleted and sanitation will suffer if the resultant untreated hard water is used to prepare cleaning solutions. At the same time, temporary hardness chemicals (bicarbonates) will precipitate to cause continuing heat transfer problems in water heaters and milk coolers.

Tests for total hardness do not indicate the specific type of hardness and, consequently, the farm water supply may contain ions other than calcium and magnesium. These may be treated with approximately the same efficiency if specific methods are applied but are not removed by simple systems designed for calcium and magnesium alone.

Ion exchange softeners will filter some particles from water but are not intended for that purpose. Thus, if the supply also has a sediment problem, filters should be installed ahead of the softener, since sediment in the exchange bed will greatly reduce the capacity of the softener. Water with a high iron concentration will form a precipitate which also will interfere with softener operation.

Sources of Supply Limitations: Water for farm use can be obtained from three general sources of supply. These include: (1) Precipitation (rain, snow, etc.); (2) surface water (exposed bodies of fresh water); and (3) ground water (water from a saturated zone in the earth).

Atmospheric water is likely to be the most pure of available supplies. When impounded in suitable cisterns, it is a source of soft, high-quality, and inexpensive water which may not need further treatment for many farm uses. When used for drinking purposes or for final rinsing of milk contact surfaces, it should be treated to destroy any pathogenic or psychrophilic bacteria.

Surface water may be defined as atmospheric water which is not collected in cisterns, but rather runs off to collect in streams, ponds or lakes, swamps, etc. Such waters will collect all types of bacteria and organic and inorganic materials as they flow over (or through) the topsoil. All such supplies should be treated by filtration and disinfection before use for domestic purposes, washing or hydrocooling of agricultural products, or in milkhouse operations.

Surface water is subject to wide fluctuations in temperature and mineral content as well as bacterial flora. Passing through decaying vegetative matter, it may pick up colors and odors which, though they may not be a deterrent to proper sanitation, may make the water objectionable for drinking and other domestic uses.

Ground water is that which exists in a saturated zone of the earth's crust. Most of this supply originates as atmospheric water. Sewage and other types of liquid waste usually have relatively little effect on ground water quality in deep formations. Surface water may be important to ground water levels in the area of rainfall but may be deposited far from the point of extraction.

The principal ground supplies are springs or wells. Quality may differ greatly between deep and shallow wells. Water from relatively deep wells is usually of acceptable bacteriological quality and can be used for drinking without treatment, although it frequently has high mineral concentrations. Shallow well water is seldom this pure. While bacteria and colloidal materials are commonly removed as water seeps through the ground, mineral substances are frequently dissolved to create waters with varying degrees of hardness. Occasionally, objectionable gases such as hydrogen sulfide may be dissolved which produce undesirable odors or tastes. More commonly, carbon dioxide is dissolved, creating acid water with an enhanced ability to dissolve minerals.

Shallow wells may yield appreciable numbers of many types of bacteria and, less commonly, yeasts. It has been reported that infectious hepatitis and typhoid fever are problems arising from contaminated shallow wells in some areas (*77*). This pollution may be caused by seepage of contaminated surface waters. Fragmented or cavernous rock formations may contain crevices which extend to the surface, particularly in limestone areas. Shallow wells may decrease in quantity (or dry up completely) under drought conditions. Wells and springs should be properly disinfected usually by chlorination after construction and after any repair or alteration to the system.

In some locations, sand and gravel strata exist below a stable water table. These strata may provide a dependable source of water similar in quality to that of shallow wells in the area. These systems are commonly located near a lake or stream; however, an adequate distance should separate the source from the system to allow for suitable filtration. The area above the infiltration system also must be protected to prevent pollution by animals or sewage (*104*).

Other Considerations Regarding Sources of Water: Farm water supplies which are obtained from municipal systems usually are free from pathogenic bacteria and objectionable odors, colors, or tastes. The primary problem with such sources, in addition to cost considerations, is related to the control of nonpathogenic microorganisms and minerals occurring in the supply.

Many farm operations utilize water from several sources during the year. Assuming the relative quality of supplies as noted above, such combinations of sources may cause problems in dairy sanitation. Sanitation chemicals are selected to soften hard water and provide sufficient reserve to remove dairy films. Several sources which are interconnected in one system and then utilized as needed during the year, may have entirely different hardness and pH relationships, greatly affecting the strength of cleaning solutions. Incomplete sanitation for even a short period can cause film development (milk and/or water) which will have a long-term effect on raw milk quality unless removed by supplemental treatment.

Objectionable Natural Constituents of Water: The objectionable foreign materials commonly present in water can be divided into several groups. These are:

(1) Suspended matter. This includes clay, silt, and sand. The first two are found chiefly in untreated surface supplies while sand is commonly associated with well supplies.

(2) Materials causing taste, odor, and color. These impurities normally occur as the result of one or more of the following: dissolved organic matter, dissolved organic gases, hydrogen sulfide, earthy constituents, algae, phenols, or other wastes. Hydrogen sulfide is more commonly associated with ground supplies, while the other impurities occur more often in surface waters.

(3) Materials causing hardness. As water moves on or through the earth, it may collect salts of calcium and magnesium, and to a lesser extent other minerals. While many of these salts are of little concern in drinking water, they can affect seriously water to be used in cleaning and cooling.

Bicarbonates, sulfates, and chlorides are the common anions in farm water supplies, while calcium, magnesium, and sodium are the most frequently encountered cations. The bicarbonates produce a condition known as temporary hardness. This is the major cause of hardness problems in farmstead water supplies, but precipitation is rapid if bicarbonates are present. A hardness film also forms when equipment is rinsed with hard water. Upon evaporation of the water, hardness minerals remain as a film on equipment.

Hardness is objectionable for most domestic uses and causes problems in dairy sanitation since precipitation of hardness chemicals (waterstone) will trap milk residues. These then harbor and provide nutrients for microorganisms which, in turn, affect both the keeping quality and the sanitary quality of the raw milk supply as measured by usual regulatory procedures. "Stone" buildups on milk-handling equipment can only be removed by special cleaning procedures.

(4) Iron, copper, and manganese. These elements are troublesome in the water supply of dairy farms. They can be deposited on milk contact surfaces during normal sanitation procedures, then be removed by milk due to its slightly acid nature. When iron and copper are present in milk in concentrations as low as 0.1 mg/l, they will contribute to the development of oxidized (cardboardy) flavors (72). These minerals may exist in the water supply itself or result from corrosion of the water pipes. Acid waters (pH<7.0) are particularly troublesome in causing corrosion and subsequent copper or iron contamination in the water.

Iron and manganese may be found in some well water supplies. When present, they cause a particularly objectionable red-brown stain which is difficult to remove from surfaces being cleaned without special techniques.

Nonpathogenic Bacterial Contaminants: Microorganisms are commonly present in surface waters and waters held in reservoirs. Coliform bacteria in a water supply have been accepted as presumptive evidence that contamination with pathogenic species is likely since isolation of every potential type of pathogen is not practical at this time. Likewise, the dairy industry has been concerned with the coliforms since they are commonly used as an indication of contamination with fecal pollutants in the vicinity of the sampling location.

Many other nonpathogenic species of microorganisms are found in farm water supplies. Although most of these are harmless, certain of them contribute to the development of colors, odors, tastes, and turbidity. Algae, diatoms, and protozoa produce odors in the water but these are seldom factors in milkhouse sanitation. One group of organisms known as "iron bacteria" actually feed on iron pipes. These slimy, mucoid cells may multiply in the presence of iron, produce undesirable flavors and clog pipes or seriously depress flow rates (*200*). Ropy milk is a classical example of a fault which may be due to contaminated water.

There is considerable recent evidence that one group of water organisms, commonly referred to as psychrophilic (cold loving) organisms, may have a considerable effect on the keeping quality of raw milk. The pychrophiles include many species capable of breaking down the fat and proteins in milk to produce serious physical and chemical changes in the product (*165*).

Research has shown farm water supplies to be of variable but generally poor quality. While the majority of water samples would be acceptable by presumptive coliform determinations, tests could indicate the supplies contained other organisms capable of affecting milk quality (*79*).

Studies have shown that coliform bacteria and most other bacteria are easily destroyed, even when water is quite turbid. While treated waters may satisfy standards for potable supplies, certain psychrophilic bacteria and other spoilage organisms may survive chlorine treatment and continue to be a factor in milk quality control (*6, 7, 77, 79, 82, 186*). Laboratory studies indicate that some of these putrefactive bacteria will survive even 10 mg/l residual chlorine (*6, 7, 79, 81*). Results with iodine treatments were similar (*6, 7, 79*). The literature shows that certain psychrophilic organisms are quite resistant to all sanitizing agents (*81*). Sublethal doses of chlorine may effect a temporary decrease in the growth of surviving organisms but the rate of increase after this temporary lag may be greater than that of the control sample (*32*). Many of these organisms grow at low levels of organic matter. They are actively proteolytic, lipolytic, or putrefactive. They grow well at temperatures barely above freezing and may have serious consequences in present milk handling methods where lengthy storage of raw milk is common. As modern milk handling methods make it likely that at least small amounts of water will enter the milk, it is evident that farm water supplies must be free of these microorganisms.

Quality considerations

Taste and Odor

The water supply should be substantially free of substances offensive to sight, taste, or smell. Taste and odor in water may result from the presence of a wide variety of substances including organic compounds, inorganic compounds, and algae. Knowledge concerning the source of taste and odor components is useful in determining what treatment, if any, is necessary to make the water acceptable.

The odor of water is usually due to the presence of dissolved gases such as hydrogen sulfide and volatile organic compounds. Threshold odor values in excess of three units (*159*) are generally considered objectionable. Dissolved inorganic salts of iron, zinc, manganese, copper, sodium, potassium, and others may be detected by taste. Limits for many of these ions are listed later in this report.

Color

The water supply should be substantially free of color. Dissolved organic material from decaying vegetation and certain inorganic matter cause color in water. Occasionally, excessive blooms of algae or the growth of aquatic microorganisms may also impart color. While color itself is not usually objectionable from the standpoint of health, its presence in excess of 15 color units (*159*) is aesthetically objectionable and suggests that the water needs appropriate treatment.

Temperature

The temperature of the water supply is not an important quality consideration for most farmstead uses. Where large volumes of water are to be used for hydrocooling farm products, however, the natural temperature can be a factor influencing its acceptability for such use.

ph

The pH of waters can range from 5.5 to 9.0 (*177*) but most surface waters fall between pH 7.0 and 8.5 (*179*) usually due to the presence of bicarbonate and carbonate ions. Waters with a pH below 6.0 can cause excessive corrosion in plumbing systems while waters with a pH above 8.5 suggest excessive sodium. Knowledge of the water pH is useful in determining necessary measures for corrosion control, sanitation, and adequate disinfection. It is recommended that the pH of farmstead water for milkhouse use fall between 6.8 and 8.5.

Total Dissolved Inorganic Compounds

Firm standards for total dissolved inorganic solids are not realistic in view of the naturally occurring difference in waters from various sources and geographical locations. The importance of total dissolved inorganic solids in farmstead waters for domestic use relates largely to taste, hardness, and laxative properties. It is desirable that the total dissolved inorganic solids not exceed 500 mg/l. Chlorides and sulfates should not exceed 250 mg/l. No general recommendations are appropriate for sodium, magnesium, potassium, phosphorus, sulfur, or calcium.

Although in excess of the above recommendations, waters containing up to 5,000 mg/l total dissolved inorganic solids can be used if alternate sources are not available. Under these conditions, however, the acceptability of the water depends upon the ionic composition of the dissolved solids and the feasibility of treatment to remove objectionable ions.

Dissolved Organic Compounds

Determination of total dissolved organic compounds in water by measurement of carbon chloroform extractable substances (CCE) is too involved and expensive to be considered for application to farmstead water supplies. If surface waters are being used, an estimate of the CCE may be obtained from nearby municipalities using the same or similar sources. If deep ground waters are being used on the farmstead, the problem of total dissolved organic compounds may be ignored unless there is reason to expect contamination.

The organic compounds of possible concern in connection with farmstead supplies are persistent chlorinated organic pesticides. Although the data currently available (*55, 120, 171*) indicate that contamination of both ground and surface water with any of these materials rarely exceeds 0.1 μg/l and, accordingly, is negligible in terms of human health, it is highly desirable that water supplies remain in such a condition. Some criteria, such as those suggested by Ettinger and Mount (*52*) are too low to be broadly applied at the present time in water quality evaluation. It is considered appropriate, therefore, that the permissible levels of specific pesticides in a farmstead water supply should not exceed the limits suggested by the PHS advisory committee, on use of the PHS drinking water standards. The work of that Committee has been described in the section on Public Water Supplies (par. 21). These recommendations are shown in table IV–5.

TABLE IV–5. Recommended Limits for Chlorinated Organic Pesticides in Farmstead Waters

Compound	Maximum acceptable concentration µg/l	Compound	Maximum acceptable concentration µg/l
Endrin	1	Heptachlor	18
Aldrin	17	H. expoxide	18
Dieldrin	17	DDT	42
Lindane	56	Chlordane	3
Toxaphene	5	Methoxychlor	35

Turbidity

The presence of suspended material such as clay, silt, finely divided organic material, and plankton contributes to the cloudiness or turbidity of water. Turbidity in excess of 5 units (*159*) is easily detectable in a glass of water and is usually objectionable for aesthetic reasons. Clay or other suspended particles may not adversely affect health, but water containing such particles may require treatment to make it suitable for certain uses. Following a rainfall, variations in the ground water turbidity may be considered an indication of surface pollution.

Trace Elements

Attention has been given only to those trace elements which commonly occur in water supplies or those which are regarded as being particularly hazardous. The development of standards for every potentially hazardous substance which may occur in a water supply is an impossible task. The user of farmstead water supplies should ascertain, however, that there are no geological or environmental conditions which render the supply unsafe due to the presence of substances not covered herein.

Table IV–6 lists the allowable concentrations of trace ions which, if exceeded, would make a water supply unsatisfactory for farmstead use.

The concentration of the trace substances summarized in table IV–7 should not be exceeded if other sources of water are available. Water to be used in milkhouse sanitation should not contain more than 0.1 mg/l of iron or copper.

Water containing more than 2.5 mg/l fluoride is detrimental during tooth formation and should not be used without suitable treatment (*12, 191*).

TABLE IV–6. Allowable Concentrations of Trace Ions in Farmstead Waters

Substances	Maximum limit mg/l	Substances	Maximum limit mg/l
Arsenic	0.05	Cyanides	0.20
Barium	1.00	Lead	0.05
Cadmium	0.01	Selenium	0.01
Chromium (hexavalent)	0.05	Silver	0.05

TABLE IV–7. Recommended Limits for Certain Trace Substances in Farmstead Waters

Substances	Recommended limit mg/l	Substances	Recommended limit mg/l
Manganese	0.05	Zinc	5.0
Iron	0.3	Fluoride	0.7–1.2
Copper	1.0	Nitrate	45.0

Radionuclides

All radiation exposure is regarded as harmful and any unnecessary exposure to ionizing radiation should be avoided. The acceptability of a farmstead water supply containing radioactive materials should be based upon the determination that the intake of radioactive substances from such water when added to that from all other sources is not likely to result in exposure greater than that recommended by the Federal Radiation Council (*56*). Supplies containing radium-226 and strontium-90 are acceptable without consideration of other sources of radioactivity if the concentrations of these radionuclides do not exceed 3 and 10 pc/l, respectively. In the known absence of strontium-90 and alpha-emitting radionuclides, the water supply is considered acceptable if the gross beta activity does not exceed 1,000 pc/l. If the gross betta activity is in excess of this amount, a more complete radiochemical analysis is required to determine that the sources of radiation exposure are within the limits of the radiation protection guides.

Pathogenic and Nonpathogenic Microorganisms

The presence of any coliform organisms in a water supply suggests fecal contamination. The common technique used to measure coliform organisms, however, is based on a probability formula and compliance with the criterion is met if the sample is found to contain no more than one coliform organism per 100 ml of water. If routine chlorination or other effective means of disinfection is used, levels up to 100 coliform organisms per 100 ml in the raw water supply can be tolerated. Coliform densities above this level may require special treatments.

It should be kept in mind that negative test results cannot be considered as an assurance of a continuously safe supply unless the results of sanitary surveys and subsequent negative tests support such a position.

In addition to limitations for coliform organisms, water used for dairy sanitation should contain no more than 20 organisms of all other types per milliliter and no more than 5 proteolytic and/or lipolytic organisms per milliliter (*111*).[1]

Determination of quality

Monitoring and Periodic Checks

Water for farmstead use should be sampled and examined for bacteriological contamination upon completion of the supply system and when the system is repaired or changed. Samples should be taken also to determine the physical and chemical characteristics of the supply at the time of initial use of the system. Bacteriological analysis should include testing for important groups of nonpathogenic bacteria in addition to usual coliform determinations.

Samples of water for farmstead use should be taken periodically during the year and analyzed for bacteriological, physical, and chemical characteristics. If there is any likelihood that composition has changed, more frequent sampling may be necessary if the source is known to be of variable quality. During a temporary shortage when water is hauled to a dairy farm producing milk under a sanitary code based on the USPHS grade A Pasteurized Milk Ordinance (*176*), it is mandatory that a sample of such water be taken each month at the point of use and submitted to a laboratory for bateriological examination. When the quality is such that treatment is necessary to meet USPHS standards described above, the farm operator or his representative should make frequent tests (at least weekly) to determine that the equipment is operating properly.

Procedures for Analysis

Procedures used in the determination of water quality factors are, for the most part, standard methods applicable in the examination of water regardless of its source or intended use. In view of this fact, methods for sampling and analysis are found in the section on Sampling and Analytical Procedures of this report.

Specific recommendations

Discussion of Limiting Criteria

Water for use by the human farm population, for washing and preparation of raw farm products for marketing, and for dairy sanitation should be potable as a minimum requirement. Also, in developing water sources, attention should be given to assure that the supply used does not contain microorganisms or chemicals which can cause product deterioration or adversely affect sanitation procedures.

Farms using multiple sources of water should keep supplies separate and have each analyzed with reference to the quality criteria previously listed. Withdrawal from each of the several sources should be planned and adjustments made in sanitation and treatments based on the composition of that water.

Many species of bacteria are capable of establishing cultures in unclean or corroded pipes. Samples of water for analysis should be taken at the outlet as well as at the source to determine the presence of any microbial buildup in piping systems. Pipes may become perforated by corrosion, or leaks may develop at pipe joints permitting polluted water to be drawn into the normal supply system.

Evaluation of Recommendations—Needs and Their Achievement

The history of American agriculture indicates that a suitable water supply for general farm use can be obtained usually with little trouble if attention is paid to developing proper sources. The use of low-quality water can normally be traced to lack of knowledge as to what constitutes an acceptable supply, rather than any inability to correct known, undesirable conditions.

Certain nonpathogenic bacteria have the ability to withstand high chlorine residuals. When such bacteria are present, they may be controlled by alternative methods.

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[1] Standard methods for the examination of dairy products. 1960. 11th ed. APHA, Inc., N.Y. Hammer, B. W., and F. J. Babel, 1957. And, Dairy bacteriology, 4th ed. John Wiley & Sons. pp. 15–16.

In some instances, water sources near bodies of salt water may be contaminated with salt due to lowering of the water table. Once contamination occurs in this manner, restoration of the underground aquifers is not considered economically feasible.

In dairy sanitation, cleaning chemicals can be selected to correct many problems of common, undesirable chemicals in the farmstead water supply. Removal requiring expensive treatment systems is unusual.

Water Treatment Possibilities, Including Economics

The quality requirements for water to be used on a farm are not difficult to meet in most cases. Treatments which render a supply potable, combined as necessary with treatments to remove undesirable chemicals, are sufficient for most ground water sources.

The use of surface water should not be considered unless ground sources are undependable or unavailable. Surface water should always be considered contaminated and individually tailored treatment processes must be used to make it safe as well as satisfactory for farm uses encompassed by this report. Farm ponds, if properly maintained, can provide raw water of high bacteriological quality requiring a minimum of treatment to be made suitable for domestic and livestock uses (*100*).

Microbial Contaminants and Their Control: The common method for controlling pathogenic bacteria has been chlorination in any one of several ways. Certain problem areas must be considered if the system is to be successful. The following are important:

(1) The chlorine demand in the raw water supply may vary greatly. This is particularly true of surface water or when it is obtained from several sources. When chlorine demand is low, the water may be objectionable to taste because of excess chlorine in the system. The operator may reduce the rate at which chlorine is fed into the system which then becomes inadequate when chlorine demand again increases.

(2) Chlorine-feeding equipment differs greatly in cost and design. Venturi systems which become inoperative may disrupt the entire water system. Sediment may be a problem in some systems and equipment should be recommended by competent authority.

(3) Chlorine mixing must be complete and an adequate residual maintained. The system must allow sufficient contact time for maximum killing efficiency. This is not possible in some types of equipment nor is it possible in systems which do not include a mixing tank as a basic component. Complete mixing is unlikely in the piping system alone (*155*).

(4) An adequate supply of chlorine must be available at all times. Chlorine residuals must be checked and equipment inspected on a regular basis. Human error and neglect are common problems in the operation of individual, small water systems.

(5) Certain water supplies may give a false picture of the efficiency of a chlorination system. Nitrites, manganic manganese, or ferric iron in water will produce a false color when a free-chlorine residue test is made. Water which is highly alkaline or very cold is more difficult to disinfect. In some hard waters, precipitates may partially clog the check valves of the feeder pump, reducing its effectiveness.

Shaw (*155*) has commented on some of the problems commonly encountered in treating individual farm water systems to remove pathogenic bacteria. He states that:

> The big problem today is not whether or not something should be done about individual water systems, but rather what and how. It is a problem that is at the same time both extremely simple and frustratingly difficult.
>
> The simple part is that the bacteriologists can tell us what kills most pathogenic organisms and the sanitary engineers can tell us what methods and equipment have been in successful use for years in municipal waterplants.
>
> The difficult part is the adaptation of proven methods and techniques, or the development of new ones, which will, at a low cost, automatically and surely perform an operation that in a municipal water treatment plant requires expensive equipment, constant maintenance, supervision, adjustment, and testing by trained personnel.

It is also reported by Shaw that about half of the individual water supplies tested in Pennsylvania were found to be polluted. Many of the water treatment devices in use are not doing an effective job even though they satisfy regulatory requirements. He points out that monthly sampling of individual water systems "seems unreasonably troublesome and expensive," yet the usual requirement of annual sampling is inadequate.

There are three common methods and many pieces of commercial equipment which may be used in the treatment of water in individual systems. The methods are chlorination, ultraviolet sterilization, and heat treatment.

Chlorination is best accomplished by the method known as superchlorination. Efficient equipment at a reasonable cost can be secured for adding chlorine to water in the proper dosage to destroy harmful microorganisms. Such chlorinators are essentially small liquid pumps that measure out a certain dosage of chlorine and inject it into the correct quantity of water. Chlorinators may be operated by an electric motor, by a belt drive from a water pump, or by a watermeter.

An advantage of an automatic chlorinator is that it can be used to add other chemicals to the water to remove manganese and iron, destroy iron bacteria, neutralize acid waters, control algae, and correct certain tastes and odors.

Ultraviolet sterilization is a practical alternative method of water treatment. Certain psychrophilic bacteria, known to be able to break down the fat and protein in milk, resist very high concentrations of chlorine (*81*). Concentrations of chlorine necessary to destroy viruses and protozoa which have formed cysts are not well understood. The latter, which are particularly chlorine resistant (*64*) may be present in ground water in areas where fractured rock or limestone channels exist. Recent developments in the design of components make ultraviolet (UV) radiation an inexpensive and generally successful method of treatment. Recently, the USPHS accepted UV purification of water if the installation includes safety devices which shut off the flow of water if the intensity of the light falls below acceptable levels. Meters have been developed to keep a permanent record of UV treatment. Ultraviolet treatment has the advantage that it will destroy all types of microbial life known to be a problem in farm water supplies (*70*).

Limitations to the UV treatment of farm water supplies include the fact that UV treated water has no residual action, thus any contamination beyond the point of treatment will pass to the finished water supply. Periodic flushing and disinfection of the water distribution system must be provided. Turbid waters will quickly coat the lamp, reducing UV intensity. If automatic signalling devices, installed to stop the flow of water, are not properly treated, such coating could occur during a period of abnormally heavy demand (as in fire-fighting). Insurance underwriters may cancel contracts when UV systems are installed if an outlet is not provided ahead of the treatment site for fire protection.

Heat treatment is satisfactory for destroying normal water flora just as UV sterilization is advantageous for treating chlorine-resistant bacteria. The system simply requires heating water to a prescribed temperature for a sufficient length of time. An ordinary water heater can be used if the temperature is high enough (*156*). Sediment or temporary hardness will cause problems unless removed prior to heating. When cool water is needed, the heat must be removed, thus creating a cost for cooling as well as heating. The water pasteurizer has been accepted in some parts of the country but is generally considered to be somewhat expensive in comparison with chlorination and UV treatment.

Removal of Iron and Manganese: Insoluble iron and iron bacteria will intensely foul the mineral bed and the valves of a water softener. Therefore, it's best to remove iron and manganese before the water reaches the softener.

Iron and manganese can be removed by a combination of automatic chlorination and fine filtration. The chlorine chemically oxidizes the iron (forming a precipitate), kills iron bacteria, and eliminates disease bacteria. The fine filter then removes the iron precipitate. Some filters may dechlorinate also. This chlorination-filtration method corrects the iron problems and assures disinfection as well.

Iron can be removed effectively from water by aeration and by some types of softening equipment.

Neutralization of Acid Water: Acidity of water is usually caused by dissolved carbon dioxide. The carbon dioxide, from decaying vegetation, forms carbonic acid. Acid water can cause corrosion of the water system and release of objectionable metallic ions. Acidity of water is easily corrected by addition of a neutralizing solution.

To correct acidity and disinfect with the same equipment, a neutralizing solution may be fed into the water supply by mixing with the chlorine solution. Satisfactory equipment for adding soda ash in powdered form is also available.

Other methods for minimizing the effect of acid water are:

(a) Installation of plastic pipe for cold-water lines when constructing new systems;

(b) Reduction of the temperature of hot water; and

(c) Removal of oxygen or acid constituents from the water.

Control of Tastes and Odors: Depending upon the cause, taste and odor can be removed or reduced by aeration or by treatment with activated carbon, copper sulfate, or an oxidizing agent such as chlorine.

Aeration is an effective treatment for water having a rotten egg odor indicating the presence of hydrogen sulfide (commonly referred to as sulfur water). To remove, spray the water into the air over a collecting basin, or cause it to flow over baffles so that the hydrogen sulfide gas will be released into the air. Protect the aeration equipment so that contaminants cannot enter the water.

Activated carbon treatment consists of passing the water through granular or powdered activated carbon which adsorbs large quantities of dissolved gases, liquids, and finely divided solids. This treatment is extremely effective in taste and odor control. Activated carbon can be used in filters available from manufacturers of water-conditioning and treatment equipment.

Superchlorination also is effective in reducing tastes and odors present in water. Add chlorine to the water in excessive amounts (superchlorination) to provide a minimum chlorine residual of 3.0 mg/l for a contact period of at least 5 minutes. Remove the excess chlorine (dechlorination) to eliminate the objectionable taste. A good method is to use filters of activated carbon.

Algae are the most frequent cause of taste and odors in farm water supply systems. To control algae, treat the water with copper sulfate or, when feasible, cover the storage unit to exclude sunlight. The amount of copper sulfate required varies with the particular species or organism involved. A dose of 0.3 mg/l (1 ounce in 25,000 gallons of water) will generally control most algal growth likely to cause trouble in drinking water. Even this small amount will damage milk flavors if the treated water is used in milkhouse sanitation without removing the copper.

Softening: Hardness of water is due, in large part, to the presence of calcium and magnesium compounds. Water dissolves these minerals as it passes through soil and rock formations.

Water softening is not usually considered necessary or economical unless the total hardness exceeds 100 mg/l. In this case, the better and easier cleaning obtained along with the savings in detergent probably will pay for the softener.

Water softeners are simple machines and the cost of operation is low. Before a water softener is installed, the water should be analyzed to determine how much softening capacity is required. Most dealers who handle water softeners provide this service.

The Water Systems Council's publication, "Water System and Treatment Handbook," summarizes methods of water treatment in a useful table (*191*).

livestock water supplies

introduction and general problem areas

Relationship of water to total diet

Domestic livestock represent an important seg- of the complex, interdependent organization of living things on earth. As plants are considered the "great anabolizers," animals are the "great converters" which provide energy and other basic necessities in forms that are both useful and palatable to mankind. It is significant that they are a part of the world's renewable sources of energy, as opposed to the fixed sources, such as fossil fuels. Because of these attributes, the future of domestic animals must be carefully guarded.

Both domestic animals and man occupy the paradoxical position of contributing to, and being affected by pollutants in their environment. Much of this environment, even for land animals, is aqueous, and water is of paramount importance as a vehicle for metabolites and their degradation products—hence the purity of water consumed by livestock has far-reaching implications. There are many ways in which livestock water supplies may be contaminated. These may be direct, as for example where ground water rises from a parent soil or rock formation having unusual mineral content—either excessive or deficient in relation to the nutrient requirements of animals. They may also be indirect in the sense that fertilizers added to aid crop production may stimulate biological growth (microbial, algal) in impounded water to the point where animals consuming that water may be affected. These materials may also produce varied effects. They may impede the husbandry of livestock either by causing death losses or by interfering with reproductive processes. They may also contaminate animal products (e.g. milk) to the point where human consumption may be objectionable. Pollutants may be of varied types including mineral salts, organic growth, parasitic organisms, pesticide and herbicide residues, and more recently, radionuclides. It is important to have some understanding of the levels of these various substances that can be safely tolerated by livestock and the levels that constitute hazards.

In approaching this study, it is axiomatic that although water is universally needed and consumed by farm animals it does not constitute their entire ingested intake. Thus, the tolerance levels that have been established for many substances in livestock feed do not accurately represent the tolerance levels in water. In this connection, some assessment of the amounts of water consumed by various species of livestock is useful; however, the literature on this subject is not voluminous. Since water is usually given *ad lib.*, it is not customary to measure its uptake by individual animals except on an experimental basis. Terminology may also sometimes be confusing. "Water consumption" usually denotes free water drunk by an animal, whereas "total water intake" includes the moisture content of the feed. The former designation is more appropriate for the purpose of this study; however, the interaction between water and dry diet cannot be ignored. Many factors influence the water consumed by livestock so that generalizations become unwise if not impossible. Some of the more obvious of these factors are species, age, and condition of animal; the coat covering (as related to evaporation losses); ambient temperature, and the nature of the diet—particularly with relation to its moisture content. With the reservations noted above, table IV–8 has been assembled as representative of approximate "normal" ranges of water consumption for various classes of livestock (*1, 85, 161*).

TABLE IV–8. Normal Water Consumption

Animal	Water consumed, gallons per day
Beef cattle, per head	7–12
Dairy cattle, per head	10–16
Horses, per head	8–12
Swine	3–5
Sheep and goats, per head	1–4
Chickens, per 100 birds	8–10
Turkeys, per 100 birds	10–15

Effect of water on plant composition

The effects of water pollutants upon livestock may be mediated directly through water drunk by the animals or secondarily through the effect of ground water pollutants upon composition of plant forages subsequently consumed. In some cases plants serve as a protective buffer against animal damage since they cannot themselves tolerate amounts of contaminants that would be hazardous to livestock. A case in point is boron which, although required by growing plants, cannot be tolerated by them in soil water concentrations of over 4.0 mg/l on a continuous basis. No evidence has been found that such a level in drinking water is injurious to animals. On the other hand, some plants take up from either soil water or the parent soil material considerably larger amounts of certain materials than animals can ingest with safety. One of the best examples of this type of situation is the "selenium accumulator" type of plant, like the genus *Astragalus*, which has been reported to contain from 1,000 to 10,000 mg/kg of selenium (*143*). When one considers that the toxic level of selenium in feeds consumed by animals on a routine basis is about 4 mg/kg, it is obvious that plant growth cannot be accepted as a valid criterion of safety to animals. A further example of dangerous contamination of water, as far as livestock are concerned, is molybdenum. In Florida, where cases of molybdenosis have occurred, the molybdenum content of ground water varied from 0 to 8.5 mg/l (*38*) and in some instances forages were produced that were so high in molybdenum that severe scouring occurred among livestock. It is perhaps unwise to deal with mineral contaminants individually as distinct entities since there are frequently metabolic interrelationships among them. It is generally accepted, for example, that molybdenum toxicity may be alleviated to a considerable extent by increasing copper content of the diet (*101*).

Other, less direct effects of water contamination upon livestock production are evidenced by the relationships of soil and irrigation water salinity to plant growth. Here the effects are measured in terms of reduced forage yield, or perhaps inability to produce certain desirable forage plants, rather than in terms of any direct action upon the animals themselves.

Fish as indicators of water safety for livestock

The presence of fish in a source of water for livestock may be an excellent measurement of toxicity and to a limited extent its acceptability from an aesthetic viewpoint. Ultimately, livestock standards may include aesthetic values applied to water used by man despite the fact that animals may consume water which is grossly contaminated with fecal organisms, animal matter, and dissolved substances available in the environment.

Considerable evidence is available in the scientific literature suggesting lower tolerance levels for various agricultural chemicals (including pesticide residues) for fish than for livestock. Accordingly, presence of living fish in agricultural water supplies indicates their safety for livestock (*105*). Some examples of individual effects in fish and animal species are included in table IV–9.

TABLE IV–9. Examples of Fish as Indicators of Water Safety for Livestock (105)

Material	Toxic-levels mg/l for fish	Toxic effects on animals
Aldrin	0.02	3 mg/kg food (poultry).
Chlordane	1.0 (sunfish)	91 mg/kg body weight in food (cattle).
Dieldrin	0.025 (trout)	25 mg/kg food (rats).
Dipterex	50.0	10.0 mg/kg body weight in food (calves).
Endrin	0.003 (bass)	3.5 mg/kg body weight in food (chicks).
Ferban, fermate	1.0 to 4.0	
Methoxychlor	0.2 (bass)	14 mg/kg alfalfa hay, not toxic (cattle).
Parathion	2.0 (goldfish)	75 mg/kg body weight in food (cattle).
Pentachlorophenol	0.35 (bluegill)	60 mg/l drinking water not toxic (cattle).
Pyrethrum (allethrin)	2.0 to 10.0	1,400 to 2,800 mg/kg body weight in food (rats).
Silvex	5.0	500 to 2,000 mg/kg body weight in food (chicks).
Toxaphene	0.1 (bass)	35 to 110 mg/kg body weight in food (cattle).

Changing patterns of livestock production have introduced some problems and variables affecting man's activity. The economic capability to produce livestock, whether it be poultry, swine, beef, or dairy cattle, in confinement creates a very practical problem of sewage disposal equal in volume to effluent from some small cities. The problem may be made acute by the concentration of wastes in a single drainageway with its implication of gross contamination of larger water systems particularly during rainfall periods. If fish are able to survive in the terminal management of water on the production premise, this may be more readily accepted as a criterion of safety than if the only visible measurement is an anaerobic, black, stinking, open pool of sewage. The latter situation is often the case and public demand is strong to induce modifications whether or not economically feasible.

It is apparent that large livestock establishments need help in designing practical waste disposal systems. The system must be able to handle odors and gases as well as solids and the net result must not create an excessive Biological Oxygen Demand (BOD) in the terminal water. Some operations avoid excess contamination of flowing water by spreading liquid manure onto fields. The BOD may be partially satisfied by introducing air under pressure into sewage, by anaerobic digestion with production of methane and other flammable gases, or by other procedures. The total nutrients available in solution, however, create problems in the aquatic environment which can readily be measured by fish livability in terminal ponds. The possibility of a marketable product of fish is a reality, but only under unusual circumstances should public fishing be encouraged.

Fish in association with livestock will not measure the presence of pathogenic, enteric, or other microorganisms except as biologic accumulators. Fish disease organisms are usually of different genera from those causing livestock diseases, although some diseases, like salmon poisoning in dogs and numerous parasitisms including fish in their life cycles, are exceptions.

Relationship between animal and human water quality criteria

Water is a vehicle for transmission of many infectious diseases (viral, parasitic, and fungal) affecting both animals and man. Generally speaking, however, it is less significant than food or other contact situations as a route of infection. Mineral and chemical contaminants of water are hazards from a health and economic standpoint for both animals and man. The quality criteria for mineral and chemical contaminants established for human water supplies have been based primarily on animal experimentation and not human tests. Similarly, the 50-percent lethal dose (LD_{50}) for most drugs for humans is derived from animal experimentation using the chick, duck (eggs), dog, swine, rat, and rabbit as test subjects. Desirable quality criteria for livestock drinking water should ultimately be no less than for man. At the same time, it must be appreciated that a large segment of the grazing livestock population obtains its water from surface sources.

Livestock are maintained in an environment where exposure to coliform and other organisms can be an everyday experience. Remarkable advances in animal production have been accomplished through management practices which have eliminated many pathogens. The more advanced the management program, the more important the need for water criteria which approximate human standards. Enteric organisms and viruses may cause serious losses where management practices allow livestock to become more susceptible to infection through lack of immunity. Nutritional factors may also change the resistance to disease. Although antibiotics in poultry and swine feeds increased weight gain and improved feed efficiency, the resulting reduction and alteration of intestinal bacteria created an environment for those organisms resistant to the antibiotics.

There is evidence also that water is a vehicle for the transmission of such diseases as colibacillosis, swine erysipelas, leptospirosis, listeriosis, salmonellosis, streptococcosis, staphylococcosis, and tuberculosis. Moreover, many fungus diseases are transmitted by water although less frequently than by other methods. Practically all of the trematode, cestode, and nematode (parasitic) infections may be waterborne. It is also suspected that many virus diseases are waterborne. Under otherwise ideal conditions for livestock, specific organisms or viruses spread by water can cause explosive epidemics and sometimes serious losses, as in the case of amoebic dysentery and waterborne diarrhea.

Not infrequently, livestock are watered from the same source which supplies the home. Here the standards must obviously be human oriented. Watering livestock may provide additional problems through float-controlled tanks which either leak or concentrate toxic substances through evaporation. Automatic float-controlled devices for swine and poultry are particularly likely to overflow and the muddy, damp environment may increase the hazard of disease. If the water supply is from deep wells and artesian aquifers, the water itself may be safe although its mineral content may differ materially from surface water of the area. When spilled on the soil, this deep-well water may create environments suitable for parasitisms, acid-fast infections, leptospirosis, and other diseases not common to the neighborhood of shallow wells and surface water supplies.

Some diseases are very dependent on water.

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Relationship between animal and human water quality criteria

Water is a vehicle for transmission of many infectious diseases (viral, parasitic, and fungal) affecting both animals and man. Generally speaking, however, it is less significant than food or other contact situations as a route of infection. Mineral and chemical contaminants of water are hazards from a health and economic standpoint for both animals and man. The quality criteria for mineral and chemical contaminants established for human water supplies have been based primarily on animal experimentation and not human tests. Similarly, the 50-percent lethal dose (LD_{50}) for most drugs for humans is derived from animal experimentation using the chick, duck (eggs), dog, swine, rat, and rabbit as test subjects. Desirable quality criteria for livestock drinking water should ultimately be no less than for man. At the same time, it must be appreciated that a large segment of the grazing livestock population obtains its water from surface sources.

Livestock are maintained in an environment where exposure to coliform and other organisms can be an everyday experience. Remarkable advances in animal production have been accomplished through management practices which have eliminated many pathogens. The more advanced the management program, the more important the need for water criteria which approximate human standards. Enteric organisms and viruses may cause serious losses where management practices allow livestock to become more susceptible to infection through lack of immunity. Nutritional factors may also change the resistance to disease. Although antibiotics in poultry and swine feeds increased weight gain and improved feed efficiency, the resulting reduction and alteration of intestinal bacteria created an environment for those organisms resistant to the antibiotics.

There is evidence also that water is a vehicle for the transmission of such diseases as colibacillosis, swine erysipelas, leptospirosis, listeriosis, salmonellosis, streptococcosis, staphylococcosis, and tuberculosis. Moreover, many fungus diseases are transmitted by water although less frequently than by other methods. Practically all of the trematode, cestode, and nematode (parasitic) infections may be waterborne. It is also suspected that many virus diseases are waterborne. Under otherwise ideal conditions for livestock, specific organisms or viruses spread by water can cause explosive epidemics and sometimes serious losses, as in the case of amoebic dysentery and waterborne diarrhea.

Not infrequently, livestock are watered from the same source which supplies the home. Here the standards must obviously be human oriented. Watering livestock may provide additional problems through float-controlled tanks which either leak or concentrate toxic substances through evaporation. Automatic float-controlled devices for swine and poultry are particularly likely to overflow and the muddy, damp environment may increase the hazard of disease. If the water supply is from deep wells and artesian aquifers, the water itself may be safe although its mineral content may differ materially from surface water of the area. When spilled on the soil, this deep-well water may create environments suitable for parasitisms, acid-fast infections, leptospirosis, and other diseases not common to the neighborhood of shallow wells and surface water supplies.

Some diseases are very dependent on water.

Leptospirosis can be spread by urine splash to the face of other animals, but spreading via water is the more common and normal situation in epidemics. A piped water supply may not affect the distribution of such diseases as anthrax, blackleg, botulism, bacillary hemoglobinuria, and footrot infections, all of which occur in circumstances involving various water-related environmental factors. For example, soil and rainfall distribution materially influence the occurrence of these diseases. Preventive management practices should include a sanitary water system which does not pond or puddle water on the yards or pastures. Such diseases as dysentery, typhoid, and cholera of man also have their counterparts in livestock production. A pathogen-contaminated water supply should no more be permitted for livestock than for the human because the separation of human and animal pathogens in their ability to cause disease is not distinct.

The economic importance of optimum water intakes by farm animals is obvious. Thus, palatability and toxicity due to dissolve mineral salts are of concern. The most abundant mineral salts present in surface and deep-well waters are the carbonates, bicarbonates, chlorides, and sulfates of sodium, potassium, magnesium, and calcium. Together they comprise 95 to 99 percent of the total mineral content of most natural waters. Water begins to decrease in palatability when the total amount of these minerals exceeds from 500 to 1,000 mg/l, depending on the nature and combination of the minerals. Beyond these limits, the water becomes increasingly unpalatable and finally toxic. The common belief that cattle and sheep are more tolerant to highly mineralized waters than poultry, swine, and horses may not be true. Limited research work indicates little species differences in salinity tolerance when the moisture content of the rations is similar.

Practical experience and a limited amount of controlled experimental work indicate that chickens, swine, cattle, and sheep can survive and remain healthy on saline waters containing up to 15,000 mg/l of minerals such as bicarbonates, chlorides, and sulfates of sodium and calcium and up to 10,000 mg/l for the corresponding salts of potassium and magnesium. The limits of tolerance to alkaline waters, those containing sodium and calcium carbonates, are around 5,000 mg/l.

Surface and underground waters nearly always contain trace amounts of toxic minerals. Of these, lead, arsenic, selenium, chromium (hexavalent forms), cadmium, silver, barium, and fluorine are cumulative poisons. When present in excess, they are not eliminated from the body fast enough to prevent the buildup of toxic levels in the bones, soft tissue, and other body parts. They thus become hazards to man who consumes them as well as to the animal which may very well survive the insult and reach market without outward noticeable effect. Many other minerals, such as salts of zinc, copper, manganese, and iron, are also present. However, they are not cumulative poisons and become toxic at much higher levels.

A quantitative mineral analysis of water is highly informative relative to its content of lead, arsenic, and other toxic minerals. In only a few cases will these minerals be present in harmful amounts. In nearly all cases, the decisive factor affecting the suitability of water will be the amount of sodium, potassium, magnesium, and calcium contained.

Since no two waters are similar in their relative content of sodium, potassium, magnesium, and calcium, no attempts have been made to determine the exact magnitude of their detrimental effects on water and feed intakes and feed efficiencies during the time required to develop tolerance to them. The detrimental effects will be roughly proportional to the total amount of these four minerals in excess of 1,000 mg/l.

Variable considerations

Geographical

The foregoing discussion has implied something of the breadth and diversity of the water pollution situation as it bears on domestic livestock. Some classification of the resultant problems is possible on the basis of the variety of factors influencing pollution.

Certain geographical areas of the United States are recognized as related to specific types of water contamination. These may be concerned with geological soil formation, or with production patterns indigenous to the areas in question. Examples of the first type are the presence of boron in natural waters of Southern California and of sulfates as leachings from gypsum and other soil minerals in several of the Western States. An indirect example of the same relationship is the effect that certain alkaline soil conditions have upon the pH of soil water and the subsequent implications for viability of livestock disease organisms. Microorganisms responsible for erysipelas in swine, sheep, and turkeys, vibrio fetus in cattle and sheep, and vibrio dysentery ("winter dysentery") of cattle all thrive in an alkaline medium (*13*).

Nitrate toxicity, while it is still imperfectly understood, tends to show some tendency toward prevalence in areas of the Great Plains having high-soil fertility and a high water table.

Sulfates and their derivatives may also be used as examples of product-oriented contamination in discharge waters from paper mills which are located in various regions of the country where geographical conditions support timber growth. Development of large-scale livestock feedlots has generally taken place in dryer regions where disease control is easier. Consequently, specific problems of water pollution related to this industry acquire a regional pattern.

Species

Some interesting species differences also exist among livestock tolerances to water pollutants. A pertinent example of these is the variable response of different types of animals to salinity concentrations. Standards developed in western Australia as safe upper limits for livestock are listed in table IV–10 (*122, 190*).

TABLE IV–10. Proposed Safe Limits of Salinity for Livestock

Animal	Threshold salinity concentration [1] TDS mg/l
Poultry	2,860
Swine	4,290
Horses	6,435
Dairy cattle	7,150
Beef cattle	10,000
Sheep (adult, dry)	12,000

[1] Total salts, mainly NaCl.

These values should not be taken as absolute, but rather interpreted as indicative of the significant species variation that exists. They were developed in a subtropical environment and may not be readily translatable to more temperate areas. Obviously, when feed is also high in salt content, a lower water salinity would be desirable. Moreover, when animals are consuming high-moisture forage they can tolerate more saline water than when they are grazing dry "bush" or "scrub."

description of major quality considerations

Discussion of individual items as they affect livestock

Mineral Salts

One of the commonest types of water contaminants is the mineral salts due to their ubiquitous occurrence and their solubility characteristics. Highly mineralized waters can cause physiological disturbances in animals including gastrointestinal symptoms, wasting disease, and sometimes death. Animals subjected to physiological stresses, such as reproduction, lactation, or rapid growth, are particularly susceptible to mineral imbalances, hence they pose a real threat to animal production. It is not prudent to generalize on overall "salt" levels in water since some salts are specifically toxic, such as nitrates, fluorides, selenates, and molybdates (*11*). "Alkalinity" of water, while it does not represent a single polluting substance, but rather a combination of various effects and conditions, is a common measurement that carries some significance. Caustic alkalinity in concentrations of 50 mg/l and 170 mg/l has been reported to cause diarrhea in chickens and other animals (*71*). The following data are pertinent to establishment of tolerance levels for specific inorganic elements or their salts.

The establishment of criteria for every potentially hazardous material which might occur in water is not feasible. Allowable concentrations of certain trace elements, as listed in table IV–11, are

TABLE IV–11. Suggested Maximum Allowable Concentrations of Certain Inorganic Elements in Farm Animals' Water Supply

Substance	Suggested maximum allowable concentration, mg/l
Arsenic	0.05
Cadmium	0.01
Chromium (hexavalent)	0.05
Lead	0.05
Selenium	0.01

satisfactory for farm use and presumably safe for livestock. Further data on specific mineral salts are listed in the subsequent discussions.

Antimony may find its way into water supplies as antimony potassium tartrate, or "tartar emetic", since this is sometimes used as a mordant in textile and leather manufacturing (*110*) and for the control of ants and other insects. The minimum lethal oral dose of this compound for rats is listed at 300 mg/kg body weight, however, horses can apparently take 5.8 g and cattle 3.8 g three times daily without harm (*124*).

Arsenic has long enjoyed notoriety as a poison, but more recently, arsenicals have found some usefulness in livestock production mainly as a coccidiostat in poultry feeding or in "dip" solutions for animals. There is also recent evidence that arsenic functions in some way to reduce selenium toxicity when present in drinking water at levels of 5 mg/l as sodium arsenate (*36*). The toxicity of arsenic depends to a considerable extent upon the form in which it occurs. Thus, LD_{50} doses for female rats are 112 mg/kg as elemental arsenic or 298 mg/kg as calcium arsenate (*60*). Wadsworth (*185*) has listed toxic dose ranges for arsenic as shown in table IV–12.

TABLE IV–12. Proposed Toxic Dose Ranges for Arsenic (185)

Animal	Toxic dose of As, g/animal
Poultry	0.05– 0.10
Dogs	0.10– 0.20
Swine	0.50– 1.00
Sheep, goats, horses	10.00–15.00
Cattle	15.00–30.00

Beryllium is a rare element unlikely to occur in natural waters, although it could conceivably be involved in effluents from metallurgical plants. Laboratory rats survived 2 years on a diet which supplied about 18 mg/kg beryllium daily. If these data are transposable to cattle, it has been calculated a cow could drink 250 gallons of water containing 6,000 mg/l beryllium, without harm (*133*).

Boron may enter water supplies naturally, from geological boron deposits, or in the form of synthetic boranes. The latter are more highly toxic (*87*). The lethal dose of boric acid varies from 1.2 to 3.45 g/kg body weight, depending on the animal species (*27*). Concentrations of 2,500 mg/l boric acid in drinking water have inhibited animal growth.

Cadmium salts are found in effluent waters of various industrial plants, including electroplating, textile, and chemical concerns. Ground water contamination of 3.2 mg/l cadmium has been reported from Long Island, N.Y. (*88*). Data on cadmium toxicities are fragmentary. The lethal dose of cadmium has been set at 0.15 to 0.3 g/kg body weight for dogs and 0.3 to 0.5 g/kg for rabbits (*124*).

Chlorides may enter ground waters from a variety of sources, including natural mineral origin, or sea water infiltration of subterranean water supplies, from oilfield operations, and from industrial effluents (papermaking, galvanizing, water-softening). Concentrations of chlorides of 1,500 mg/l in livestock water supplies has been reported safe for cattle, sheep, swine, and poultry.

Chromium, in common with most of the trace elements, appears to serve some essential function for animals in small concentrations, but also poses a toxicity problem if present in excess. As data for establishing a specific criterion for livestock use are inadequate, the criterion for farmstead water supplies appears to be satisfactory for livestock as well (*66*).

Cobalt: The range between adequate levels of cobalt required by animals in extremely low concentrations and toxic levels is quite wide. Accordingly, cobalt toxicity is a rare problem and is more likely to arise from contamination of the dry matter of the diet than from water contamination. Cobalt toxicity is evidenced by a striking polycythemia in various species of animals (*86*). Levels of 100 mg/l cobalt in drinking water for rats has been reported to cause tissue damage (*124*).

Copper: Little information is available on toxic levels of copper in drinking water for livestock although the toxic effects of copper have been extensively studied. One is led to the conclusion that most copper toxicities are feed-related rather than water-related. There are, however, a number of opportunities for copper contamination of water supplies since copper in various forms is widely used in agriculture. One reference indicates that levels of about 160 mg/l copper inhibits water intake for turkeys whereas 500 to 600 mg/l is "harmful" to turkeys when such water is the only drinking water available (*67*). Even these levels, however, are generally higher than those recommended for control of fungus infections in turkeys, suggesting that any damage would be accidental.

Fluorine may become a ground water contaminant from underlying strata containing fluorides and may perhaps enter in effluents from certain types of manufacturing processes. The latter, however, are more likely to be airborne than waterborne. The U.S. Public Health Service recommends rejection of drinking water supplies containing from 1.4 to 2.4 mg/l, depending on prevailing temperatures (*175*). It is noteworthy that addition of up to 500 mg/l of fluoride to either the feed or drinking water for cattle did not raise the fluoride level in their milk above 0.5 mg/l (*157*).

Iron: Reports on direct toxicity resulting from iron in water are not available. However, it has been suggested that intake of water by livestock may be inhibited if it is high in iron (*164*).

Lead may arise as a contaminant of ground waters, both from natural sources (deposits of galena) or as a constituent of various industrial and mining effluents. A complication as far as lead is concerned in livestock waters is caused by the fact that it is a cumulative poison. There is a report of chronic lead poisoning among animals by 0.18 mg/l of lead in soft water (*198*), and there is fairly general agreement that 0.5 mg/l of lead is the maximum safe limit in a drinking water supply for animals (*129*). There is a considerable difference in the relative toxicities of various forms of lead.

Magnesium: Some salts of magnesium, particularly magnesium chloride, may contaminate ground water supplies as a component of waste waters from oil wells, road runoff, and industry. Certain magnesium salts such as the sulfate caused scouring or diarrhea among livestock; however, the level they can tolerate safely appears to be fairly high. It has been reported that livestock will tolerate 2,050 mg/l of magnesium sulfate in their drinking water without laxative effects (*9*).

Manganese: Toxicity data on manganese contents in drinking water are not readily available. However, cattle are reported to have suffered no serious effects following dosages of up to 600 mg/kg in their diet for 20 to 45 days.

Mercury: Contamination by mercury may result from natural soil sources, tailings from lead mining, or from a variety of chemical wastes. Like lead, mercury is a cumulative poison and its continued ingestion should be carefully controlled. Wide variations in responses to various mercury salts make generalizations dangerous. For example, the LD_{50} value for mercuric chloride for rats is 37 mg/kg, while that for mercurous chloride was 210 mg/kg (*5, 158*). The use of mercury in American agriculture has been restricted.

Molybdenum salts can be significant water pollution problems. Plant growth is not a sufficiently sensitive criterion of molybdenum occurrence to be used as an indicator of water safety for livestock since some plants can apparently accumulate fairly large stores of molybdenum. Effects of molybdenum toxicity are aggravated by conditions of copper deficiency in livestock. In Nevada, with unusual local forage copper levels, molybdenosis occurs only above forage levels of 5 to 6 mg/kg for cattle and 10 to 12 mg/kg for sheep (*46*). Although specific data on molybdenum toxicity from drinking water sources are not readily available, some Florida waters where molybdenum toxicity has occurred have contained up to 8.5 mg/l molybdenum (*38*).

Nitrates: Heavy application of nitrogenous fertilizer can lead to leaching of nitrates in percolating ground waters (*128*). Nitrates may also be supplied as end products of aerobic stabilization of organic nitrogen in sewage lagoons. There are some indirect effects which complicate the nitrate contamination picture. In ruminant animals, nitrates may be reduced in the rumen by the microflora to nitrites which then exert toxic effects on the animals. When present in waters in high concentrations, nitrates may also stimulate growth of undesirable plants.

Despite considerable interest in the potential problems of nitrate toxicity, there are few specific data. Campbell and others have reported methemoglobinemia in cattle receiving water containing 2,790 mg/l of nitrate.

Selenium: Another case where plants cannot serve as satisfactory indicators for animals is presented by selenium, as previously indicated. In some cases drainage water from irrigated areas has been found to contain appreciable quantities of selenium (*143*). Also, some selenium reaches ground water by leaching from seleniferous plants.

Only in isolated cases has evidence been presented that selenium occurs in water in sufficient amounts to produce selenosis in man or animals. Moreover, water containing high concentrations of selenium is generally unpalatable to livestock (*143*). Unlike certain of the other elements considered, selenium poses an additional problem in that it is readily transmitted through the mammary gland to the milk (*147*).

Selenium is an essential trace mineral and of special concern in the small safety range between requirement (1 to 2 mg/kg of feed) and toxicity (5 mg/kg).

Sodium: Various salts of sodium occur in considerable concentrations in the earth's crust and these may be leached into surface waters. Also, in some areas there is considerable production of sodium salts from deep wells of the petroleum industry. High concentrations of various sodium salts in water are deleterious to both plants and animals. Waters containing 2,700 mg/l of Na (as NaCl) were toxic to chicks (*168*) and a threshold limit of 2,000 mg/l of sodium for livestock has tentatively been suggested (*160*). There are considerable differences in the sensitivities of different species of livestock to sodium concentrations in water.

Sulfate: A threshold limit of 1,000 mg/l for sulfates in drinking water has been suggested by Stander (*160*). There are reports that levels of 2,104 mg/l of sulfate caused progressive weakening and death in cattle (*2*) and 2,500 mg/l of sulfate caused diarrhea in dogs (*19*).

Vanadium: It is questionable that significant levels of vanadium will occur in surface waters. Little data are available on toxic effects of vanadium in water *per se;* however, increased mortality on a seleniferous ration has been attributed to addition of 5 mg/l of vanadium (*115*).

Zinc: There are very many opportunities for contamination of water by zinc, both from natural sources and from its many industrial uses. Animals appear to tolerate significant amounts of zinc. Rats fed water containing 50 mg/l of zinc show no harmful effects (*3, 199*).

Organic Wastes and Algae: A vast number of organic compounds too numerous to list here can find their way into soil and surface waters as contaminants. Since the most numerous and perhaps the most important of these will be discussed in the section on herbicides and pesticides below, they will not be further described here. Attention is directed, however, to contamination of waters used for livestock by organic matter, particularly algal growths.

It is difficult to generalize on effects of algae because they differ markedly. Some types of green algae serve as food for certain aquatic species and their harvest for use as livestock feeds has been suggested. Other types of algae, notably the blue-green type, are patently toxic and can cause death both of aquatic species and of livestock. Probably the first report of livestock poisoning by "water bloom" was recorded in Australia in 1878 (*59*) and similar descriptions have appeared since. In late July 1946, numerous deaths occurred among animals drinking algae-contaminated water from upper Des Lacs Lake in North Dakota (*25*). Canadian studies have implicated *Aphanizomenon, Anabaena,* and *Anacystis* blooms in such situations. The first-named genus was much more plentiful than the other two and it was apparently the major factor in toxicity. Animals were reported to have died shortly after drinking water from a lake containing these plants and a suspension of the algae killed laboratory mice and rats within 20 hours.

A freshwater dinoflagellate, *Gymnodinium* was apparently responsible for mass death of plankton-feeding shad (*126*). Fish poisoned by phytoplankton and consumed by birds have been reported to cause their death (*189*), presumably a similar fate could befall animals and man.

Pesticides and Herbicide Residues: Pesticide and herbicide residues have been a cause of concern to livestock owners from the time the agriculturalist first used these materials to protect crops or livestock from pests or disease. The cheapest diluent and spreading agent is water and even relatively insoluble compounds are formulated so they may be dispersed in water. Leftover formulations in open containers may be consumed by thirsty livestock, or may enter the water supply through improper dispositions. To a lesser degree, a water supply may be accidently contaminated with these compounds, leading to poisoning. In the presence of microorganisms, silt, or other colloidal or suspended matter in water, many compounds accumulate in the nonaqueous substances. These, rather than the water itself, when assimilated, provide the poisoning effects which assume increasing importance in water supplies today. *To date, however, no reported example has been found of toxicity in livestock due to pesticides or herbicide contaminants of water supplies in general.*

Pesticides and herbicides, along with other compounds which have dangerous properties when out of natural balance, are called economic poisons. If these poisons occur in food, they may also be considered as adulterants or additives. In addition to the loss in healthy condition, productivity, reproductivity, or death, the producer may suffer further loss through condemnation of meat, milk, or other products before they reach the ultimate consumer. Water, much more than the terrestrial environment, has great mobility and can carry economic poisons and adulterants to areas remote from the origin. It is imperative that drinking water quality be maintained so that intolerable levels of either economic poisons or adulterants in livestock or their products will not occur. Such levels do not necessarily endanger livestock health, it should be noted.

The problem of accumulated pesticides in animal tissue is complicated by the similarity of pathological changes induced by naturally occurring dysfunctions, some of which are not clearly understood. Potentiation of toxicity may occur particularly in young and old animals as the result. The effects of stress and some dysfunctions related to steroid hormones may cause diseases in poultry which are also induced by organic phosphates. The interplay of arsenic in the phosphorus metabolism and the role of copper in phosphorus-molybdenum interplays indicates the complexity which can be influenced by residues.

Before 1940, the principal insecticides were compounds of arsenic, lead, lime, sulfur, and fluorine. Herbicides included the arsenicals, copper compounds, oils, and chlorates. All of these compounds have toxic effects and poisoning continues to be a problem when these materials are handled improperly. Criteria for water, on the other hand, recognize that in the absence of demonstrable disease these compounds should be disregarded.

Herbicides which contaminate water supplies fall into two general categories: those which affect the metabolism and are toxic to animals, and growth regulators of plants. The most important is probably sodium arsenite which is still used for reasons of economy. Mercurial compounds used as fungicides may occasionally enter water supplies. Pentachlorophenol and various derivatives have wide uses as herbicides, fungicides, and insecticides, but apparently the reactivity of these compounds in the presence of soil or other organic matter is such that toxicity to livestock in water seldom follows. Sulfur dioxide is a well known general protoplasmic poison, but it is more toxic as a gas than in solution. Herbicides which act as growth regulators in plants, causing derangements in plant organization and function, are not usually a threat to livestock. The organic herbicides are primarily toxicants of plants and usually have little toxic effect on other forms of life. Generally, they are less toxic than the solvents, surfactants, granules, or other adjuvants used in their formulation (*151*).

Since 1940, a number of organic insecticides have come into general use. As in the case of inorganic compounds, the action is often directed at some important tissue or metabolic function so that toxicity is influenced by the reactivity of the target tissue as it is in turn acted upon or reacts in the whole organism. The net result of the use of organic insecticides sometimes becomes a race between dosage which will kill and resistance of the host which will protect. It is seldom that acute poisoning of livestock is anything but accidental, but today's public attitude is that livestock water as well as livestock food shall not result in unwholesome residues in meat or other animal products. It may be enough to follow the rule that when the insecticide is used properly, no unusual or long time residue problems will follow. But a much wiser course to follow is to use biodegradable insecticides where possible and to phase out those which have a tendency to accumulate.

If it is true that the principal action of the organic insecticide is to bring about a derangement of a metabolic pathway or enzyme system, then it follows that under some conditions such anomalies may occur naturally. Therefore, the mere presence of an insecticide, such as DDT, in the serum or fat of a diseased animal is not proof that the DDT is responsible for the effect. On the other hand, there is a point beyond which the amount of DDT or other adulterant may not occur without representing a threat to health or causing financial loss due to an accumulation in excess of the legal tolerance for the compound.

Microbiological Pathogens: Water has assumed a major role through the ages in the dissemination of infectious bacteria, protozoa, and viruses. Man, more than livestock, has profited from knowledge of waterborne diseases. Grazing animals herded on common pastures come in contact with organisms which find in the environment the factors for a complete life cycle. Very few pathogenic microorganisms can resist desiccation, although some form spores or encyst. Waterborne infections arise through contamination of water supplies, life cycles involving a water phase, or through organisms with pathogenic capabilities adapting to growth and reproduction in water.

Water quality, including pH, mineral, and organic composition, may be very important in the distribution of infectious diseases. Scientific interest is usually directed at the whole problem with little attention given to the water phase. Some diseases are so water oriented that attention is directed at the quality and characteristics of the water environment as a factor in the distribution of disease. This interest is increasing as the ecology of waterborne diseases becomes of greater concern.

Enteric microorganisms, including the vibrios and amoebae, have a long record as water polluting agents. Chlorination, filtration, and other water treatments are directed at making water safe, but total microbial elimination in natural water appears to be an impractical procedure for man, let alone livestock.

The spread of animal infections through fecal contamination of the environment is a constant threat, but epidemiological evidence should support more criteria which directly relate specific diseases to water. The *Escherichia-Aerobacter* group of enterics is so widely distributed in nature, feed, water, and the general environment, that contamination of the intestinal tract can hardly be avoided. When they escape from these innocuous locations, as they sometimes do, to cause urinary disease, abscesses, and mastitis, they are very potent pathogens. Their invasiveness is low and unless some stress is involved infections are generally regarded as accidents. In contrast, *Salmonella* are more invasive and the carrier state is easily produced and persistent, but often without any general evidence of disease. This means that waterborne epidemics follow the introduction of specific microorganisms into the environment; e.g., where untreated sewage continually enters the water supply.

Water criteria directed against pathogenic microorganisms are divisible into two general areas of concern. The purely mechanical spread of microorganisms by way of water is very important, since desiccation is destructive of most living agents. The mobility of water also increases the chance of spread with greater dispersion of diluted but infective doses of pathogenic organisms. There is a more important aspect of water and water management which deserves greatly expanded study. The virulence of microorganisms is influenced by their environment. When a pathogen enters an aqueous environment, its ability to infect a new host may be influenced by water quality. The reports of waterborne disease substantiate this situation and serve as the principal basis for criteria. With the substantial scientific base for chemistry, soil microbiology, ecology, and geology available to the agricultural community, the obvious presence of water-related disease in one farm area or region and its absence in another should serve as a basis for comparison.

One of the best examples of water-related disease is bacillary hemoglobinuria, caused by an organism found in western areas of North and South America. This organism resembles *Clostridium novyi*, and may be classed in several species, *Cl. hemolyticum*, *Cl. sordellii*, the Newhall strain, and possibly others. It has been linked with liver fluke injury, but is not dependent on the presence of liver flukes. Once the disease has been properly diagnosed, the characteristic liver infarct is not easily confused. The particular concern has been the spread of this disease to new areas in the Western States. Far from an indiscriminate spread, each new premise is like the endemic areas which have alkaline, anaerobic soil-water environments in which the organisms have a soil phase outside the host animals. This disease may make its appearance in new areas of the West when these areas are cleared of brush and irrigated. To avoid this problem, western irrigation waters should be managed to avoid cattail marshes, hummock grasses, and other environments of prolonged saturation. The significant ecological distinction is measured by pH which must persist in alkaline ranges usually around pH 8.0.

The anthrax organism, *Bacillus anthracis*, is found in a soil environment above pH 6.0. The organism forms spores which, in the presence of adequate soil nutrients, again vegetate and grow. The spore is most likely the cause of infection, coming from an "incubator area" of killed grass found in the pasture where the loss occurred (*183*). Some very rich alluvial soils may lack the grass-kill feature, but these soils at the time of losses are powdery and dry. The killed grass is brown rather than blackened, a significant difference from water-drowned vegetation in general.

The spread by water of disease caused by drinking water containing spores has never been proved. Bits of hide and hair waste may be floated by water downstream from manufacturing plants, but very few outbreaks have been reported through this source. Numerous outbreaks studied in recent years have always had the "killed grass" potential. The organism and spore are nonmotile and sink in quiet water to the mud, where they are destroyed by biological competition. It is a soil organism not adapted to survival in water.

A relatively new and widespread disease entity in the United States, leptospirosis, is probably the most intimately water-related disease problem today. Criteria for the control of this disease are simple with some exceptions. The pathogenic leptospira leave the infected host through urine. They lack protection against drying and direct animal-to-animal spread occurs through urine splash to the eyes and nostrils of another animal. This is most likely to occur in dogs, cattle, and possibly swine. Rodents are a most common source of leptospira. When caught, their voided urine may infect man and contamination of damp forage by rodent urine may cause infection in cattle. Infection by leptospira may not always cause very serious disease, as serological testing of livestock indicates widespread exposure often without observable disease. Some serological types are more virulent for cattle and swine and, more important, cause the carrier problem. One of these, *Leptospira pomona,* occurs with such regularity that, when found in man, a livestock source is immediately sought. Similarly, another serotype, *Leptospira canicola,* occurs in dogs, coyotes, and jackals and these are thought of when outbreaks occur. Most leptospira have rodent sources with some species acting as true carriers.

The relationship of leptospirosis to water in the infectivity cycle is many times direct; that is, water which is contaminated by leptospira in urine infects by way of water consumed, splashed, or inhaled by man or animals. Birds apparently do not enter into the leptospira cycle.

An indirect water relationship also exists when mineral composition and pH influences continued motility of voided leptospira. Even if growth and multiplication does not occur, motile leptospira are a threat for some time in this water environment. Thus, most episodes of leptospirosis are traceable to swimming holes, ricefields, and natural waters of definable pH and mineral composition. The source of the leptospira is often relatively remote in time and distance which on an epidemiological basis indicates prolonged survival and vitality in the leptospira. Active programs of study of water survival were carried on in Montana and Washington and have continued in Illinois, Iowa, and Louisiana. In these States, water pH is often neutral or alkaline within the criteria for leptospira motility and survival. For leptospira control, livestock cannot be allowed to wade in water. Indirect contamination of water through sewage is unlikely, although free-living leptospira occur in such an environment.

Water plays a vital role in the creation of environments leading to other anaerobic diseases of livestock. The organisms causing these diseases are the *Clostridia* and are important through spore formation and production of toxins. For the organism, the toxins are probably nothing more than food gathering and survival enzymes, but in the animal they cause pronounced nervous system derangements, tissue coagulation and liquefaction, blood hemolysis, and food poisoning. *Clostridia* range through many species, some of which have no destructive characteristics. Although some, such as *Clostridium perfringens* and *Cl. tetani,* may become adapted to an enteric existence in animals, almost all are soil adapted. Diseases associated with the soil include gas gangrene, botulism, blackleg of cattle, bacillary hemoglobinuria, and tetanus. Rich organic mud, rotting vegetation, and decaying animal matter serve as ready sources of these organisms. Soil in a dried form contains spores, since growth occurs in wet phase where oxygen is reduced through utilization by other organisms. These spores are resistant to heat and canned foods which are not acid or sterile may allow the growth of the *Clostridia* which cause disease.

Water management to avoid oxygen depletion serves to control the anaerobic problem. Mineral content and pH are undoubtedly important factors but these are very seldom factors which should or could be controlled. A system of dykes and water level management for oxygen control in the Bear River Marshes of Utah has reduced botulism of wild birds. This system may ultimately fail, however, through silting and growth of water vegetation. Temporary and permanent areas of anaerobic water environment are dangerous to livestock; some only a few feet wide are found from time to time. These areas of water management on the farm are important, but control is usually temporary and often only after livestock loss from the anaerobic toxins or organisms. Livestock should be barred from consuming blackened water not adequately oxygenated.

The role of water in dissemination of viruses is confused by the total ecological picture of the several virus-host relationships. Recent advances in virus study and nomenclature has made previous systems of classification obsolete and any criteria for viral pollution of water should recognize these changes. Viruses cannot multiply except in a suitable living system and a variety of biological phenomena limit this to a very narrow range of host cells. They resemble spore-forming bacteria in that the spore stage does not grow and multiply outside a suitable environment. The resemblance ends here as the bacterial spore returns to a vegetative form in the presence of nutrients and a suitable environment. In water, the presence of viruses represents a dilution which increases progressively through volume change and degradation of the virus particle.

The epidemiology of virus infections tends to incriminate direct contact; e.g. fomites, mechanical, and biological vectors, but seldom water supplies. No clear distinction exists between fomites and sewage nor should one be made. On-the-farm management of water to avoid dissemination of viruses is compounded by the use of water in the removal of manure prior to the use of disinfectants or other biological control procedures. It may, therefore, be an oversimplification that viruses generally can be disregarded in water criteria. Episodes of diseases and epidemiological studies following them may indicate from time to time that sewage contaminated water supplies are incriminated in outbreaks. In herd management of livestock virus diseases, direct contact, manure contamination, and water contamination are interlinked and must usually be treated as one problem.

Viruses are classified by size, ether sensitivity, tissue effects (which include viruses long known to cause recognizable diseases, such as pox and hog cholera), and by other criteria. The first two are important in water criteria, since organization of the infective virus particle and ether sensitivity reflect the susceptibility of the virus particle to degradation in a hostile environment. Small size and ether resistance very likely indicate a greater threat of water transmission over distances; more complex particles with lipid envelopes destroyed by ether may derive benefit from moisture, but are susceptible to degradation by enzymes and electrolytes in the sewage environment. No purpose would be served by listing all viruses, but some of those which are ether resistant may call to mind the relationship of these viruses to sewage contamination. These viruses are listed in table IV–13.

TABLE IV–13. Ether-Resistant Viruses

- Picornaviruses:
  - Polioviruses.
  - Coxsackie viruses—
    - Group A.
    - Group B.
- Enteric cytopathic human orphan (ECHO) viruses.
- Rhinoviruses.
- Picornaviruses of lower animals.
- Foot and mouth virus (not present in United States).
- Teschen's disease of swine (not present in United States).
- African horse sickness (not present in the United States).
- Bluetongue virus of sheep and cattle.

Parasitic Organisms: Parasites serve as pollutants of water supplies when part of their life cycles involve a phase in water. Water supplies in general carry animal forms, which are much reduced in numbers by alum or other precipitation, settling, sand filtration, and chlorination. After such treatment, very few parasitic forms can survive the effects of dilution and soil filtration. Natural waters, whether on the surface or underground, may play an active role in parasitism, dangerous not only to livestock, but to man as well.

A careful distinction may be made between the presence of free-living forms and parasites in water. Livestock consume myriads of microorganisms found in surface water and even very clear underground water may actually contain many microscopic forms. These organisms may be digested, but sometimes they may be found in lesions where their presence suggests they might be related to the cause.

Parasitic protozoa include numerous forms which are capable of causing serious livestock losses. Most outbreaks are accomplished by direct spread from animal to animal, but rain water and overflow of piped water supplies may mechanically spread the infection. Once manure enters biologically active environments, such as streams, ponds, or overflow vegetated areas, these organisms rapidly lose their capability of causing disease outbreaks. Very important in human water criteria, these organisms may justifiably be disregarded.

Some of the most important parasitic forms for livestock water criteria are the various flukes which develop as adult forms in man and livestock. Important ecological factors include presence of snails and vegetation in the water, or vegetation covered by intermittent overflow. This problem is very serious in irrigated areas, but only when snails or other intermediate hosts are available for the complete life cycle. Fluke eggs passed by the host, usually in the manure (some species, in the urine), enter the water and hatch into miracidia. These seek out a snail or other invertebrate host where they develop into sporocysts. These transform into redia which in turn may form other redia or several cercariae. The cercariae leave the snail and swim about in the water where they may find the final host, or may encyst on vegetation to be eaten later. The life cycle is completed by maturing in a suitable host and establishment of an exit for eggs from the site of the attachment. It is not unusual for the fluke to develop in an unsuitable site for egg elimination and unusual tissue reactions sometimes follow location in these aberrant sites.

Flukes may generally be eliminated in the host by medication or isolation, control of snails, and control of vegetation. An unusual aspect of the problem is water control. In areas of Florida where fluke of cattle was previously unknown, mineral water flowing from artesian wells furnished a suitable environment for snails. This was followed by fluke problems when carrier cattle were brought to the pasture. The solution was to regulate the artesian flow into tanks to conserve the artesian pressure in the area. These measures also showed that the black water of the swamps did not support the proper snail host. Water criteria for livestock disease control, therefore, include pH differences, mineral composition of water, and other biological factors measurable in water quality itself.

Tapeworms of livestock, including poultry, do not commonly utilize a water pathway. A tapeworm of man does utilize a copepod and fish in its life cycle.

Roundworms include numerous species which may use water pathways in their life cycle. The appearance of these so-called, free-living nematodes in a piped water supply is a cause for much concern, but is probably of little health significance. However, moisture is an important factor in the life cycle of many roundworms and livestock are maintained in an environment where contamination of water supplies is a possibility every day. It is usually thought that roundworm eggs are eaten, but water-saturated environments provide ideal conditions for maintaining populations of these organisms and their eggs.

Parasitic roundworms probably evolved through evolutionary cycles exemplified by the behavior of the genus *Strongyloides*. Their life cycle is primarily a soil-to-host phase, but serious *Strongyloides* problems evolve along drainageways through the washdown of concrete feeding platforms and other housing facilities for livestock. although the classification of the *Strongyloides* implies a reasonably restricted host range for each species, this may be more environmental than genetic. Certainly, the range of activity of *Strongyloides* as parasites of insects, crabs, amphibians, and reptiles as well as mammals, indicates their capabilities as pollutants of water.

Most parasitic roundworms complete their life cycles without entering into a water phase, but mosquitoes, blackflies, and other intermediate hosts which may be associated with water management are sometimes involved. The Guinea worm, *Dracunculus*, is dependent upon water, as the adult lays eggs only when the host comes in contact with water. Man, dogs, cats, or various wild mammals may harbor the adult and the larva develop in *Cyclops*. The life cycle is thus maintained in a water environment when the *Cyclops* is swallowed by another suitable host.

Criteria for water concerning roundworms would not be complete without mentioning "horsehair worms." Eggs are laid by the adult in water or moist soil. The larva encyst and if eaten by an appropriate insect will continue development to the adult stage. The cycle may be interrupted and if eaten again by another insect the growth to adult form will be resumed. Worms do not leave the insect unless they can enter water. The life cycle is completed as free-living adults in water.

The prevention of water-born parasitisms depends on interruption of the parasite's life cycle. The most obvious is to keep livestock out of water which carries the means of perpetuating the cycle. Treatment for the removal of the parasite from the host and destruction of the intermediate host are the usual measures of control. Measures for the eradication of parasitic diseases usually require area or regional control programs. The insidious nature of parasitisms, the lack of spectacular mortality, or other evidence of disease in livestock result in general unawareness of the extent of these problems.

Radionuclides: All radiation exposure is regarded as harmful and any unnecessary exposure to ionizing radiation should be avoided. The acceptability of livestock water supply containing radioactive materials should be based upon the determination that the intake of radioactive substances from such water when added to that from all other sources is not likely to result in exposure greater than that recommended by the Federal Radiation Council (*56, 57*). Supplies containing radium-226 and strontium-90 are acceptable without consideration of other sources of radioactivity if the concentrations of these radionuclides do not exceed 3 and 10 pc/l, respectively. In the known absence of strontium-90 and alpha-emitting radionuclides, the water supply is considered acceptable if the gross beta activity does not exceed 1,000 pc/l. If the gross beta activity is in excess of this, a more complete radiochemical analysis is required to determine that the sources of radiation exposure are within the limits of the radiation protection guides.

Monitoring and Measurement: Chemical analysis of ground and surface waters for minerals is feasible and is an integral part of good livestock management. The monitoring of surface waters for other chemical toxicants (pesticides, herbicides, etc.) which may occur at sporadic intervals (due to usage) is very difficult. Thus, the use of fish indicator ponds at the terminal watersheds is undoubtedly an economical safety precaution that should be encouraged.

Method of analysis is extremely important. The organic and inorganic contents of water influence the presence of pesticides and because these compounds are biologically active, they tend to accumulate in certain phases of the aquatic environment. As the result of alteration of the environment, altered levels of pesticides may appear in an active biological role. Biological accumulations represent the greatest variabilities which affect the method of analysis.

The Agricultural Research Service of the Department of Agriculture seeks to develop morbidity and mortality records of livestock losses. Criteria for waterborne diseases are dependent upon mass statistics for losses which relate the incidence of disease to the water environment. Laboratory studies provide evidence on which to base criteria. The occurrence of disease as the result of ecological situations which involve water serve to prove the validity of the laboratory observations. Without this mass of epidemiological information, concepts which are not applicable or unnecessarily expensive may be perpetuated in relation to water management. In reference to the diseases (virus, parasitic, bacterial, or fungal) transmitted by water, reliance should be placed upon epidemiological studies to define the source of contamination and to develop the remedial measures for control.

irrigation water supplies

introduction

Impact of irrigation on U.S. agriculture

Irrigation is an important factor in providing food and fiber requirements of the Nation's population. Irrigation farming not only increases productivity of croplands, but also provides flexibility which enables shifting from the relatively few dryland crops that are grown without irrigation to many other crops which may become greater in demand. Irrigation also creates new employment opportunities in processing and marketing agricultural products.

Among the multipurposes for which water resources are developed and used, irrigation is the largest single-purpose beneficial consumptive use. Therefore, water quality criteria for irrigation become more and more significant as water resource developments increase within each river basin. Early irrigation developments in the arid and semiarid West were largely along streams where only a small part of the total annual flow was put to use. Such streams contained dissolved solids accumulated through the normal leaching and weathering processes with only slight additions or increases in concentration resulting from man's activities. Additional uses of the resource may have concentrated the existing dissolved solids, added new salts, contributed toxic elements, microbiologically polluted the streams, or in some other way degraded the quality of the water for irrigation and most other consumptive uses. More intensive development in recent years and the generally short water supply in most western streams has accentuated water quality deterioration in a downstream direction. The significance of establishing water quality criteria for irrigation can be evaluated best by examining: (1) the impact of irrigation on long-term food and fiber production in the United States, and (2) the effect of water quality deterioration on that production.

An estimated total of 458 million acres of cropland in the United States during 1966 was utilized for crop production, of which about 44 million acres, located largely in the Western States, were irrigated. This irrigated acreage, amounting to about 10 percent of the total cropland, provides about 25 percent of the total value of all crop production. Value of production during the crop year 1959, the latest year for which census data are available, amounted to about $55 per acre for all cropland in comparison to about $150 per acre for irrigation land.

For the most part, irrigated farms produce crops that cannot be grown successfully in the West under dryland conditions.

From the value standpoint, irrigation's greatest contribution is in the category of fruit, vegetable, and other specialty crops. The environment of the irrigated western areas is especially favorable for these crops. Most of the commercial production of apricots, artichokes, honeydew mellons, hops, lemons, olives, dates, figs, garlic, nectarines, prunes, English Walnuts, almonds, and filberts come from the irrigated areas of the Western States. During late fall, winter, and early spring, the warm irrigated valleys of the Far West and Southwest grow most of the Nation's supply of fresh vegetables. The off-season production of these fresh vegetables and fruits adds variety and balance to the Nation's diet.

Soil-Plant-Climate interrelationships

Evaluation of water quality criteria for irrigation purposes must take into consideration the interactive effects of soil, plant, and climate. Each of these factors is highly variable. Yet, they are important in determining the quality of water that can be used for irrigation under a specific set of conditions.

Soil

The physicochemical properties of a soil determine the root environment that a plant encounters following an irrigation. The soil consists of an organo-mineral complex which has the ability to react both physically and chemically with constituents present in irrigation water. The degree to which these added constituents will leach out of a soil, remain available to plants in the soil, or become fixed and unavailable to plants depends largely on the soil characteristics.

In irrigated areas, a water table frequently exists at some depth below the ground surface, with a condition of unsaturation existing above it. During and immediately following periods of precipitation or irrigation, water moves downward through the soil to the water table. At other times, water losses through evaporation from the soil surface and transpiration from plants (evapotranspiration) may reverse the direction of flow in the soil so that water moves upward from the water table by capillarity. The rate of movement is dependent upon water content, soil texture, and structure. In humid and subhumid regions, this capillary rise of water in the soil is a valuable water source for use by crops during periods of drought.

Evapotranspiration removes pure water from the soil leaving the salts behind. Since salt uptake by plants is negligible, salts accumulate in the soil. A favorable salt balance in the root zone can be maintained by leaching through the use of irrigation water in excess of plant needs. Good drainage is essential to prevent a rising water table and salt accumulation in the soil surface and to maintain adequate soil aeration.

Soils vary greatly in their physicochemical properties; therefore, the resultant effect of a given irrigation water quality on the plant root environment will also be quite variable.

Plant

Plants can be affected in two ways by irrigation water quality. First, where sprinkler irrigation is used, foliar absorption or adsorption of constituents in the water may be detrimental to plant growth or consumption of affected plants by man or animals. Secondly, where surface or sprinkler irrigation is practiced, the effect of a given water quality on plant growth is determined by the composition of the equilibrium soil solution. This is the growth medium available to roots after soil and water have reacted.

Plants vary considerably in their tolerance to water quality constituents. Genetic considerations apply not only to differences between species, but to varietal differences as well. Many species and varieties of plants have been observed for tolerances to salinity, trace elements, pesticides, and pathogens. A good start has been made in classifying plant tolerance to salinity, but much remains to be learned regarding the effects of irrigation water.

Climate

Irrigation is necessary for intensive crop production in arid and semiarid areas and is used to supplement rainfall in humid areas. The need for irrigation is determined to a large extent by rainfall and snow distribution; but temperature, radiation, and humidity are also significant factors.

The effects of water quality characteristics on soils and on plant growth are directly related to the frequency and amount of irrigation water applied. The rate at which water is lost from soils through evapotranspiration is a direct function of temperature, radiation, wind, and humidity. Soil and plant characteristics also influence this water loss. Aside from water loss considerations, water stress in a plant as affected by the rate of evapotranspiration will determine the plant's reaction to a given soil condition. For example, in a saline soil at a given water content, a plant will usually suffer more in a hot, dry climate than in a cool, humid one. Considering the wide variation in these climatic variables over the United States, it is apparent that water quality requirements also vary considerably.

Rainfall and snowmelt are also significant because they affect not only the amount of available water in the soil, but may also be a factor in leaching constituents applied in irrigation water out of the plant root zone. Because precipitation patterns are so variable, they influence the degree of hazard presented by use of water of a given quality.

The soil, plant, and climate variables must be considered in developing criteria for evaluation of irrigation water quality. A wide range of suitable water characteristics is possible even when only a few variables are considered. Even under favorable conditions of soil, drainage, and environmental factors, too-sparing applications of high quality water with total dissolved solids of less than 100 mg/l would ultimately damage sensitive crops such as citrus fruit, whereas with adequate leaching water containing 500 to 1,000 mg/l might be used. Under the same conditions, certain salt-tolerant field crops might produce economic returns using water with more than 4,000 mg/l. Criteria for judging water quality standards must take these factors into account.

Past and current trends in water quality classification

From the very beginning of irrigation in the United States, farmers have observed differences in water quality that have influenced their crops. In some areas, they soon learned to bypass water that contained excessive amounts of sediment or that originated from tributaries known to be saline.

Means (*106*) observed in 1903 that safe salinity limits previously set for irrigation water were too low. Since that time, various schemes for classification of the suitability of water for irrigation have been developed. Scofield (*152*) discussed increasing soil solution salinity through the use of saline irrigation water and recognized the need for use of leaching water and adequate drainage. He established a classification system ranging from excellent to unsuitable based upon the concentration of chlorides and sulfates. He strongly emphasized that the classification was applicable to a specific region considering crops, soil, climate, and the quantity of irrigation water relative to rainfall.

Some of the later schemes of classification attempted to establish ratings of "average" conditions having general applicability. In all cases, the interpretation of the suitability of water for irrigation use was largely empirical. Current trends in research are based upon relating quality of irrigation water to specific soils and crops for specific irrigation methods (*195, 196, 197, 181*). A knowledge of the basic mechanisms involved is fundamental to the prediction of irrigation water effects on soils and plants. No single set of criteria can currently be established to evaluate water quality characteristics for irrigation purposes. It is the purpose of the following discussion to point out the various soil-plant-water-climate interrelationships and how they apply to specific water quality characteristics. Where possible, criteria or guidelines will be designed for specific characteristics.

water quality considerations for irrigation

Effects on plant growth

Irrigation is practiced primarily for the purpose of increasing economic returns from agriculture. Successful sustained irrigated agriculture, whether in arid regions or in subhumid regions, requires skillful water application based upon the characteristics of the land and the requirements of the crop. Through proper timing and adjustment of frequency and volumes of water applied, detrimental effects of poor quality water may often be mitigated.

Undesirable water quality characteristics can affect plant growth either directly or indirectly. Plants may be affected directly by either the development of high osmotic conditions in the plant substrate, or by the presence of a phytotoxic constituent in the water. In general, plants are more susceptible to injury from dissolved constituents during germination and early growth stages (*17*) than at maturity. Plants affected during early growth stages may result in complete crop failure or severe yield reductions. Effects of these undesirable constituents may be manifested in suppressed vegetative growth, reduced fruit development, impaired quality of the marketable product or a combination of these factors. The presence of sediment, pesticides, or pathogenic organisms in irrigation water, which may not specifically affect plant growth, may affect the acceptability of the product. Another aspect to be considered is the presence of elements in irrigation water which are not detrimental to crop production, but may accumulate in crops to levels which may be toxic to animals or humans.

Plant growth may be affected indirectly through the influence of water quality on soil. For example, the adsorption by the soil of sodium from water will result in a dispersion of the clay fraction. This decreases soil permeability and often results in a surface crust formation which deters seed germination and emergence. Soils irrigated with highly saline water will tend to be flocculated and have relatively high rates of infiltration (*23*). A change to waters of sufficiently lower salt content will reduce soil permeability and rates of infiltration by dispersion of the clay fraction in the soil. This hazard increases when combined with high sodium content in the water. Much depends upon whether a given irrigation water is used continuously or occasionally.

If irrigations are applied frequently enough, and with sufficient extra amounts to leach salts from the root zone to maintain a favorable growth environment, irrigation water with relatively high salt concentrations may be used indefinitely. The degree to which a saline water can be used to irrigate a given soil is closely related to the drainability of that soil.

Other irrigation water quality considerations may affect plant growth. Temperature of the water, if excessively high or low, and its resultant effect on the soil temperature in the root zone, could depress plant growth. Soil aeration and oxygen availability may be a factor deterring plant growth if water having high BOD values is used although no specific information is available.

Osmotic Effects

The effect of salinity, or total dissolved solids, on the osmotic pressure of the soil solution is one of the most important water quality considerations. This relates to the availability of water for plant consumption. Plants have been observed to wilt in fields apparently having adequate water content. This is usually the result of high soil salinity creating a physiological drought condition. Specifically, the ability of a plant to extract water from a soil is determined by the following relationship:

$$TSS = MS + SS$$

In this equation, the total soil suction (TSS) represents force with which water in the soil is withheld from plant uptake. In simplified form, this factor is the sum of the matric suction (MS), or the physical attraction of soil for water, and the solute suction (SS), or the osmotic pressure of the soil water.

As the water content of the soil decreases due to evapotranspiration, the water film surrounding the soil particles becomes thinner and the remaining water is held with increasingly greater force (MS). Since only pure water is lost to the atmosphere during evapotranspiration, the salt concentration of soil solution (SS) increases rapidly during the drying process (*91*). Since the matric suction of a soil increases exponentially on drying, the combined effects of these two factors can produce critical conditions with regard to soil water availability.

The dissolved solids or saline content of the soil solution results from natural dissolution of soil minerals and primarily from that added as irrigation water or fertilizers. Water moves downward primarily through gravitational and capillary forces until it approaches a state where further movement is slow; then moves back toward the surface as a result of evapotranspiration. With adequate leaching, however, excess water passes through the root zone carrying the salt towards the ground water. Soil salinity in the root zone will vary between irrigations, but may, under certain circumstances, present a stable pattern over long periods of time.

Plant growth is related to salinity level of the soil solution within the root zone. In assessing the problem, criteria must be developed for assessing the salinity level of the soil solution. It is most difficult to extract the soil solution from a moist soil within the range of water content available to plants. It has been demonstrated, however, that salinity levels of the soil solution and their resultant effects upon plant growth may be correlated with salinity levels of soil moisture at saturation. The quantity of water held in the soil between field capacity and the wilting point varies considerably from relatively low values for sandy soils to high values for soils high in clay content. The U.S. Salinity Laboratory developed the concept of the saturation extract to meet this need (*181*). This involves the addition of demineralized water to a soil sample to a point at which the soil paste glistens as it reflects light and flows slightly when the container is tipped. The amount of water added is reasonably related to the soil texture. For many soils, the water content of the soil paste is roughly twice that of the soil at field capacity and four times that at the wilting point. This water content is called the saturation percentage. When the saturated paste is filtered, the resultant solution is referred to as the saturation extract. The salt content of the saturation extract does not give an exact indication of salinity in the soil solution under field conditions because soil structure has been destroyed, nor does it give a true picture of salinity gradients within the soil resulting from water extraction by roots. Although not truly depicting salinity in the immediate root environment, it does give a usable parameter which represents a soil salinity value which can be correlated with plant growth.

Salinity is most readily measured by determining the electrical conductivity (EC) of a solution. This method relates to the ability of salts in solution to conduct electricity and results are expressed as millimhos (mhos × 10^{-3}) per cm at 25 C. Salinity of irrigation water is expressed in terms of EC, and soil salinity is indicated by the electrical conductivity of the saturation extract (EC$_e$).

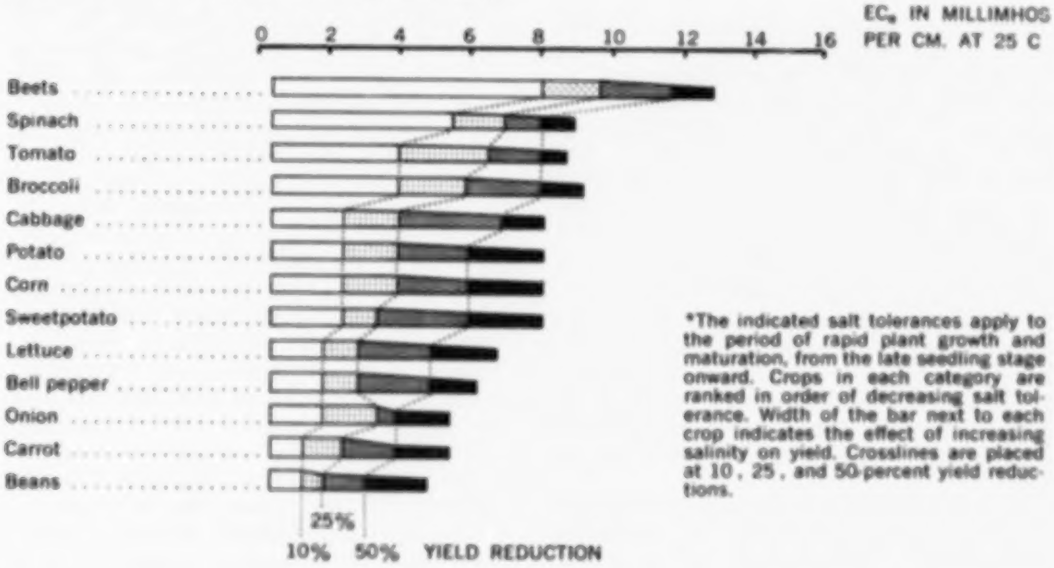
Temperature and wind effects are especially important as they directly affect evapotranspiration. Periods of high temperature or other factors, such as dry winds, which increase evapotranspiration rates, not only tend to increase soil salinity but also create a greater water stress in the plant. The effect of climatic conditions on plant response to salinity was demonstrated by Magistad, et al. (*99*). Some of these effects can be alleviated by more frequent irrigations to maintain safer levels of soil salinity. Particular problems occur where high rates of evapotranspiration occur on soils with low infiltration rates so that it may be sometimes virtually impossible to replace the soil moisture rapidly enough during the crop growing season to prevent stress.

Plants vary in their tolerance to soil salinity and there are many ways in which salt tolerance can be appraised. Hayward and Bernstein (*65*) point out three: (1) the ability of a plant to survive on saline soils—salt tolerance based primarily on this criterion of survival has limited application in irrigation agriculture, but is a method of appraisal which has been used widely by ecologists; (2) the absolute yield of a plant on a saline soil—this criterion has the greatest agronomic significance; (3) relative yield on saline soil compared to nonsaline soil—this criterion is useful for comparing dissimilar crops whose absolute yields cannot be compared directly. The U.S. Salinity Laboratory (*181*) has used the third criterion in establishing the list of salt tolerance of various crops shown in table IV–3 (p. 117). These salt tolerance values are based upon the conductivity of the saturation extract (EC$_e$) expressed in mmhos/cm at which a 50-percent decrement in yield may be expected when compared to yields of that plant grown on a nonsaline soil under comparable growing conditions.

Work has been done by many investigators, based upon both field and greenhouse research, to evaluate salt tolerance of a broad variety of plants. In general, where comparable criteria were used to assess salt tolerance, results obtained agree quite well with those shown in table IV–14.

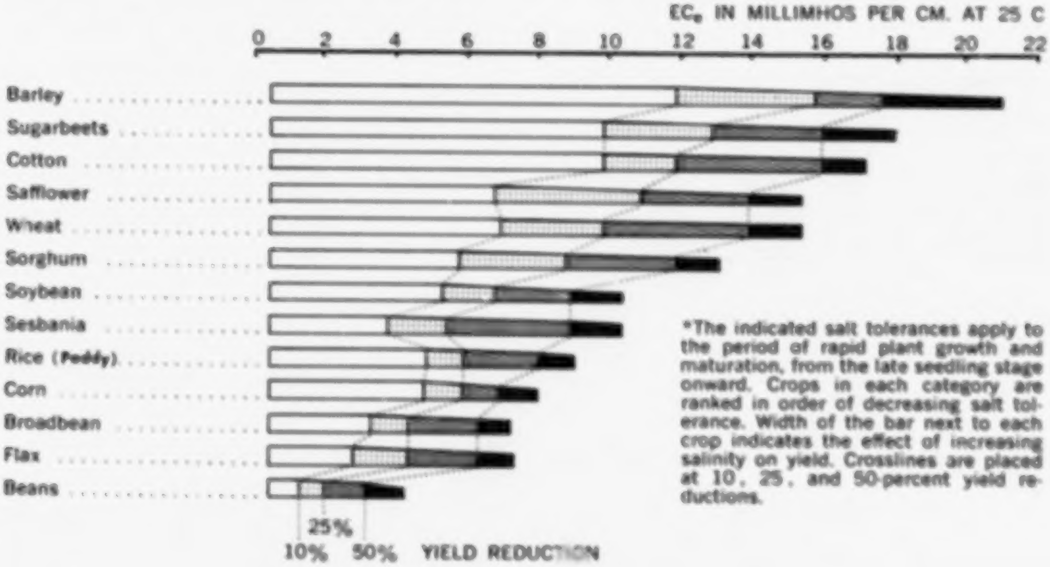
Early investigations considered the question of how increasing salinity levels in the substrate affect plant growth i.e., is there a threshold concentration at which damage to the crop will occur

FIGURE IV-1. Salt tolerance of vegetable crops*



*The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seedling stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10-, 25-, and 50-percent yield reductions.

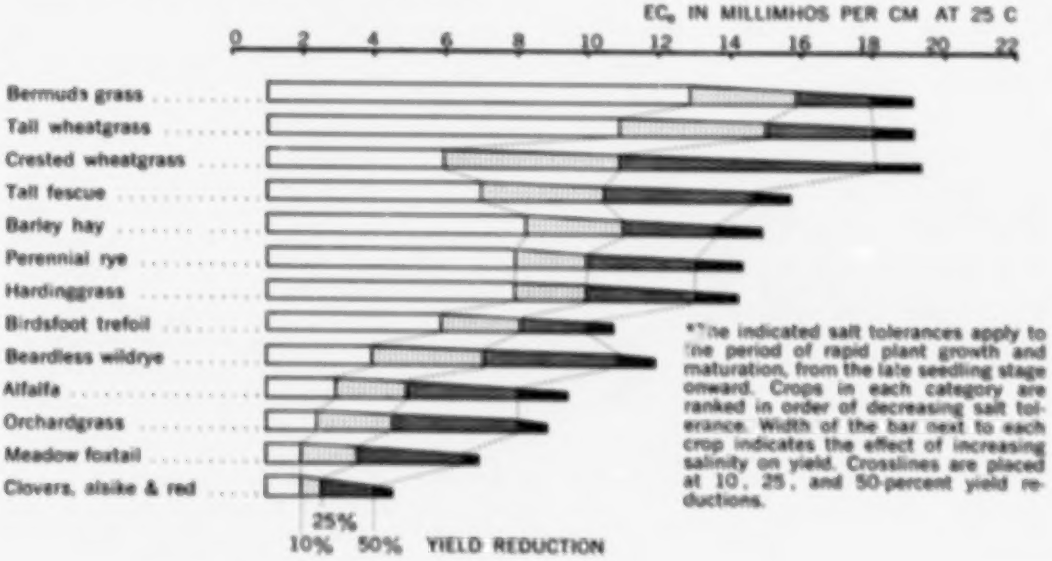
FIGURE IV-2. Salt tolerance of field crops*



*The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seedling stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10, 25, and 50-percent yield reductions.

only if that threshold were exceeded? Most studies indicated that some damage began with any increase and that there was no threshold where damage first appeared or became markedly worse. Recent data by Bernstein (*14*) give EC values causing 10, 25, and 50-percent yield decrements for a variety of field and forage crops from late seedling stage to maturity, assuming that sodium or chloride toxicity is not a growth deterrent. These values are shown in figures 1, 2, and 3. The

FIGURE IV-3. Salt tolerance of forage crops*



*The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seedling stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10, 25, and 50-percent yield reductions.

TABLE IV–14. Relative Tolerance of Crop Plants to Salt, Listed in Decreasing Order of Tolerance[1] (181).

High salt tolerance	Medium salt tolerance	Low salt tolerance
VEGETABLE CROPS		
$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Garden beets Kale Asparagus Spinach	Tomato Broccoli Cabbage Bell pepper Cauliflower Lettuce Sweet corn Potatoes (White Rose) Carrot Onion Peas Squash Cucumber	Radish Celery Green beans
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$	$EC_e \times 10^3 = 3$
FIELD CROPS		
$EC_e \times 10^3 = 16$	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Barley (grain) Sugar beet Rape Cotton	Rye (grain) Wheat (grain) Oats (grain) Rice Sorghum (grain) Corn (field) Flax Sunflower Castorbeans	Field beans
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 6$	
FORAGE CROPS (in decreasing order tolerance)		
$EC_e \times 10^3 = 18$	$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$
Alkali sacaton Saltgrass Nuttall alkali-grass Bermuda grass Rhodes grass Rescue grass Canada wildrye Western wheat-grass Barley (hay) Bridsfoot trefoil	White sweet-clover Yellow sweet-clover Perennial rye-grass Mountain brome Strawberry clover Dallis grass Sudan grass Hubam clover Alfalfa (California common) Tall fescue Rye (hay) Wheat (hay) Oats (hay) Orchardgrass Blue grama Meadow fescue Reed canary Big trefoil Smooth brome Tall meadow oatgrass Cicer milkvetch Sourclover Sickle milkvetch	White Dutch clover Meadow fox-tail Alsike clover Red clover Ladino clover Burnet
$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$	$EC_e \times 10^3 = 2$
FRUIT CROPS		
Date palm	Pomegranate Fig Olive Grape Cantaloupe	Pear Apple Orange Grapefruit Prune Plum Almond Apricot Peach Strawberry Lemon Avocado

[1] The numbers following $EC_e \times 10^3$ are the electrical conductivity values of the saturation extract in millimhos per centimeter at 25 C associated with 50-percent decrease in yield.

data suggest that the effects of EC_e values producing 10 to 50-percent decrements (within a range of EC_e values of 8 to 10 mmhos per cm for many crops) may be considered approximately linear, but for nearly all crops the rate of change in yield per unit change in EC_e, $\frac{\Delta y}{\Delta EC_e}$, either steepens or flattens slightly as the yield decrements increase from less than 25 to more than 25 percent. Bernstein (*14*) also points out that most fruit crops are more sensitive to salinity than are field, forage, or vegetable crops. Rootstock and varietal differences in salt tolerance of fruit crops are so large that it would be meaningless, for most, to give crop tolerances. The data also illustrate the highly variable effect of EC_e values upon different crops and the nonlinear response of some crops to increasing concentrations of salt.

In considering salt tolerances of crops, it should be noted that EC_e values are used. These values are correlated with yields at field moisture content. If soils are allowed to dry out excessively between irrigations, yield reductions are much greater since the total soil water stress is a function of both matric suction and solute suction and increases exponentially on drying. Good irrigation management can minimize this hazard.

Relative salt tolerance values may vary according to stage of growth (*17*). The germinating seedling is usually most sensitive to salinity as salt tends to accumulate in the surface few inches of soil. This was demonstrated for a group of grain and pasture plants in west Australia (*113*). Bernstein (*14*) points out that some plants, such as sugar beets, are sensitive to salinity during germination; others are affected more during early seedling growth, and well-established plants will usually be more tolerant than new transplants.

Salt tolerance may affect the marketable portion of the plant. In some instances, vegetative growth is more affected than fruiting and vice versa (*8, 75, 95*).

A 50-percent yield decrement may be within the profitable production range for field and forage crops in certain cases; but a yield decrement as little as 15 percent, or a normal yield accompanied by a deterioration of quality, might be sufficient to eliminate most of the profits from fruit and vegetable enterprises having a narrow margin of income over costs.

Nutritional Effects

Plants require a balanced nutrient content in the soil solution to maintain optimum growth. Use of saline water for irrigation may or may not significantly upset this nutritional balance depending upon the composition, concentration, and volume of irrigation water applied.

Some of the possible nutritional effects were summarized by Bernstein (*14*) as follows:

> High concentrations of calcium ions in the soil solution may prevent the plant from absorbing enough potassium, or high concentrations of other ions may affect the uptake of sufficient calcium.
>
> Different crops vary widely in their requirements for given nutrients and in their ability to absorb them. Nutritional effects of salinity, therefore, appear only in certain crops and only when a particular type of saline condition exists.
>
> Some varieties of a particular crop may be immune to nutritional disturbances while other varieties are severely affected. High levels of soluble sulfate cause internal browning (a calcium deficiency symptom) in some lettuce varieties, but not in others. Similarly, high levels of calcium cause greater nutritional disturbances in some carrot varieties than in others. Chemical analysis of the plant is useful in diagnosing these effects.
>
> At a given level of salinity, growth and yield are depressed more when nutrition is disturbed than when nutrition is normal. Nutritional effects, fortunately, are not important is most crops under most saline conditions; when they do occur, the use of better adapted varieties may be advisable.

Many variables are involved and each adverse condition must be diagnosed and treated accordingly.

Phytotoxic Substances and Specific Ion Effects

In addition to the effect of total salinity on osmotic soil-plant relations, individual ions may have varving effects on plant growth. These ions include both common and trace elements occurring naturally in irrigation water, those introduced by man's activities, and those which enter the soil solution through a reaction between the soil and the irrigation water. Considerable information is available regarding the effects of nutritional balance of the major plant nutrients. Although complicated by interactive effects of soil and plant characteristics, these nutritional effects are not as serious as phytotoxicity which may be caused by trace elements or specific ions.

Trace elements are those which normally occur in water or soil in very small quantities. Some may be essential for plant growth in very small amounts while others are nonessential. Some of these elements do not occur naturally in most waters or soils, but will be discussed here since they may enter water supplies as a result of industrial pollution.

When an element is added to the soil in toxic amounts, it may combine with it to give either of two results. First, it may decrease in concentrations so that it is no longer toxic. Second, it may increase the store of that element in the soil. If the process of adding irrigation water containing a toxic level of the element continues, a steady state will be approached with time in which the amount of the element leaving the soil in the drainage water will equal the amount added with the irrigation water, and no further change in concentration in the soil will occur.

In many cases, these elements are held very strongly by soils and in some cases, they may be toxic in relatively low concentrations. Therefore, irrigation water containing toxic levels of trace elements may be added for many years before steady state is approached. A situation exists then where toxicities may develop in years, decades, or even centuries from the continued addition of polluted irrigation waters. The time would depend on factors apart from properties of the water itself. Changes in technology and economy could easily alter circumstances significantly in such a long time.

Genetic differences in tolerance of plants to different elements or ions has been mentioned. Variability among species is well recognized. Recent investigations by Foy (*58*), working with soluble aluminum in soils, has demonstrated that there is also variability among varieties within a given species. This suggests the possibility of breeding varieties to minimize phytotoxicity which may result from a constituent in irrigation water.

Research dealing with effects of trace elements on plant growth does not permit, in general, any conclusions regarding threshold values beyond which specific plants will react unfavorably. Most studies have been carried out with several plant species in sand or solution cultures under a wide variety of environmental conditions. It is difficult to extrapolate from these sand and solution cultures to soil conditions. Toxic limits determined in solution cultures might apply to irrigation water if it were not for the fact that soil conditions could influence the element's availability to the plant.

Comprehensive reviews of literature dealing with trace element effects on plants have recently been published (*20, 35, 105*). Another reference (*68*) deals with reactions of trace elements in soils. Additional research is needed to predict reactions between ions in irrigation water and various soil types, and the resultant effect on various plant species.

In developing a workable program of acceptable limits for trace element pollution of irrigation waters, three considerations should be recognized:[1]

(1) The inherent difficulty of establishing generalizations. Many factors affect the uptake of and tolerance to trace elements. The most important of these being genetic variability of plants and animals, reactions within the soil, and nutrient interactions, particularly in the plant.

(2) A system of tolerance limits must, to the greatest extent possible, provide sufficient flexibility to cope with the more serious factors above.

(3) At the same time, restrictions must be defined, as precisely as possible.

To translate these considerations into workable recommendations, two types of soil groupings that may be irrigated are defined:

(a) Lands having a significant fraction of well-drained soils classified as sands, loamy sands, or sandy loams.

(b) Lands made up principally of finer textured soils and generally more slowly drained.

Individual minor element limits for water to be used on type 'a' lands are calculated assuming that steady state may be approached in a relatively short period of time and, therefore, that the concentration in irrigation waters approximates that of the soil solution. In areas where irrigation water accounts for most of the water applied to a field, the values may have to be adjusted downward to allow for concentration in the soil.

Upper limits that may be set for minor element tolerances in water for type 'b' lands are somewhat more arbitrary. They are drawn largely from maximum safe fertilizer additions that might be applied to soils under the most favorable conditions for fixing the element in the soil. The term "short time" used in table IV–15 means a period of time as long as two decades.

It is beyond the scope of this report to present a critical literature review on phytotoxic ions. Some references are cited to illustrate both the importance and the complexity of the problem. Emphasis must be placed, however, on research needs. Due to the vast scope of the problem, it is recommended that research be initiated as problems arise to derive specific recommendations. The following list of trace element effects indicate in part the potential problem and suggested trace element tolerances for irrigation waters are shown in table IV–15.

Aluminum: Aluminum toxicities to plants have been reported for both acid and alkaline conditions, but are probably of little consequence at near-neutral pH values. One milligram per liter is taken as the tolerance limit, even though several reports of toxic effects have been observed at 0.5 mg/l (*35*). The reason for this is that even sandy soils could be expected to reduce aluminum toxicities somewhat and management practices could be used to avoid marginal toxicities.

Arsenic: Arsenic may be present in fairly high concentrations without inducing injury to some plants such as lemons and sudan grass (*35*), but toxic effects on other species have been observed down to 1 mg/l (*105*). This value is selected as the tolerance level here, but a better understanding of the effects of management practices on the uptake of arsenic might indicate that a higher value could be used.

TABLE IV–15. Trace Element Tolerances for Irrigation Waters

Element	For water used continuously on all soils	For short-term use on fine textured soils only
	mg/l	mg/l
Aluminum	1.0	20.0
Arsenic	1.0	10.0
Beryllium	0.5	1.0
Boron	0.75	2.0
Cadmium	0.005	0.05
Chromium	5.0	20.0
Cobalt	0.2	10.0
Copper	0.2	5.0
Fluorine	(1)	(1)
Iron	(1)	(1)
Lead	5.0	20.0
Lithium	5.0	5.0
Manganese	2.0	20.0
Molybdenum	0.005	0.05
Nickel	0.5	2.0
Selenium	0.05	0.05
Tin	(1)	(1)
Tungsten	(1)	(1)
Vanadium	10.0	10.0
Zinc	5.0	10.0

[1] See text.

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[1] Basic information on trace elements was supplied by J. F. Hodgson of the U.S. Soil, Plant, and Nutrition Laboratory, Ithaca, N.Y.

Beryllium: Beryllium is toxic to both animals and plants. Growth of beans has been inhibited at 0.5 mg/l (*20*), and this value is selected as the tolerance limit. Beryllium toxicity will be moderated by reaction with soils, but because it represents a relatively serious problem, its limits for water use even for type 'b' land should be restricted to 1 mg/l until better information is available on its uptake from soils.

Boron: Boron is an essential plant micronutrient almost up to concentrations of 0.5 mg/l in irrigation water. However, boron in irrigation water has caused destruction of, or damage to, sensitive crops when concentrations in the irrigation water are somewhere between 0.5 and 1.0 mg/l. Most of the work on boron, done under the leadership of Eaton (*49*), found a range of tolerance of crops, as shown in table IV–16. Water containing more than 4 mg/l of boron is generally unsatisfactory for all crops. In general, sensitive crops will show slight to moderate injury at boron levels of 0.5 to 1.0 mg/l; semitolerant, 1.0 to 2.0 mg/l; and tolerant crops, 2.0 to 4.0 mg/l. In terms of content in the soil saturation extract, a limit of 0.7 mg/l of boron is considered safe. Probably the effect varies inversely with the percentage of applied water that is passed through the root zone, but this has not been evaluated. Most problems of excess boron have been encountered in waters derived from the coast range mountains of California and from the Hot Creek area in the Owens Valley of California on the eastern slope of the Sierra Nevada Mountains.

Cadmium: Cadmium toxicities have been implicated in hypertensive diseases of man. Its contribution to pollution, therefore, bears very close scrutiny. Present understanding of the problem is sufficiently limited so that cadmium will definitely require reappraisal as evidence accumulates for or against its toxicity and as understanding of its behavior in the soil-plant-animal chain is improved. The tolerance limit of 0.005 mg/l is suggested assuming: (1) reported toxicities are valid (*88, 149, 150*); (2) cadmium behaves similarly to zinc in its uptake by plants and reactions with soil. It is very likely that higher levels of cadmium could be regulated by appropriate management practices; but in the absence of yield depression, farmers have little inducement to employ such practices.

Chromium: Both the chromic and chromate ions display toxicities. Use of large amounts of chromium for processes, such as tanning, increase the importance of controlling this element.

Tolerance to the two ions varies with plant species, but more sensitive plants are adversely affected at about 5 mg/l for each ion (*35*).

The chromic ion could be expected to combine fairly strongly with neutral soils so that class 'b' soils could likely tolerate considerably more chromic ion than the above value. There is not sufficient information available on chromate ion to recognize the presence of type 'b' situations for this ion. Furthermore, the possibility of oxidizing chromic to chromate ions is too great to include water of a higher chromium content for irrigating alkaline soils of type 'b' lands even when the chromic ion is present in the water, until further information is available.

Cobalt: Cobalt toxicities have been observed on several species grown in sand culture. On the other hand, field occurrence of cobalt toxicity is rare. The tolerance limit suggested here is somewhat higher than the 0.1 mg/l cobalt which has been observed to be toxic to tomato plants. It is felt that management practices should be capable of relieving marginal toxicities of this element (*105*).

Copper: Copper toxicities have been observed at copper concentrations as low as 0.1 mg/l in nutrient solution (*35, 105*). A value of twice this is taken for the tolerance limit for water for type

TABLE IV–16. Relative Tolerance of Plants to Boron (181)

[In each group, the plants first named are considered as being more tolerant and the last named more sensitive.]

Tolerant	Semitolerant	Sensitive
Athel (Tamarix asphylla)	Sunflower (native)	Pecan
Asparagus	Potato	Black walnut
Palm (Phoenix canariensis)	Acala cotton	Persian (English) walnut
Date palm (P. dactylifera)	Pima cotton	Jerusalem artichoke
Sugar beet	Tomato	Navy bean
Mangel	Sweetpea	American elm
Garden beet	Radish	Plum
Alfalfa	Field pea	Pear
Gladiolus	Ragged Robin rose	Apple
Broadbean	Olive	Grape (Sultanina and Malaga)
Onion	Barley	Kadota fig
Turnip	Wheat	Persimmon
Cabbage	Corn	Cherry
Lettuce	Milo	Peach
Carrot	Oat	Apricot
	Zinnia	Thornless blackberry
	Pumpkin	Orange
	Bell pepper	Avocado
	Sweet potato	Grapefruit
	Lima bean	Lemon

'a' lands. Copper combines strongly with most soils as evidenced by the many soils that have been treated for decades with copper sulfate as a fungicide without displaying copper toxicities. Only water irrigating sands very low in organic matter would need to remain classified for use on type 'a' lands. Limits for water to be used on type 'b' lands could safely vary up to at least 5 mg/l.

Iron: Iron is not likely to be a problem with irrigation waters. In those instances where imbalances due to excess iron develop, they can be controlled with management practices.

Fluoride: The most serious effect of fluoride is not its effect on plant growth, but the ultimate effect on the consuming animal including man. The uptake of fluoride by plants is restricted both by a combination of the element with soils, favored by low pH, and a discrimination against fluoride by plant roots (*20*). Some plant species do accumulate large amounts of fluoride, but for the most part they are not consumed by man or livestock. The principal pathway for fluoride poisoning then is through direct imbibition of toxic waters or plant accumulation of fluoride from the air. No limits are proposed at this time, but it is recommended that it be placed in a warning category to be considered as specific cases arise.

Lead: Results from adding lead to nutrient solutions are somewhat contradictory (*35, 105*). Toxicities have been reported from additions of as little as 1 mg/l. But considerably higher levels have been used in some cases without injury. Since even sandy soils can be expected to adsorb lead, the tolerance limit of 5 mg/l is proposed.

Lithium: Crops sensitive to sodium are also sensitive to lithium. Most crops can tolerate 5 mg/l and this limit is proposed for water to be used on type 'a' lands (*18, 20*). The same limit is proposed for water to be used on type 'b' lands, since it might be expected that a steady state will be approached within a period of years on most soils.

Manganese: Manganese toxicities have been observed down to 0.5 mg/l, but a great deal af variation occurs among species and conditions of nutrient imbalance. With suitable management practices, it should be possible to tolerate up to 2 mg/l for nearly all species of plants.

Molybdenum: Molybdenum presents a particularly unique problem in that ground waters frequently carry levels of the element that give rise to plant concentrations toxic to cattle. In nutrient solution and soil solution measurements, 0.01 mg/l molybdenum in solution will produce legumes containing in order of 5 mg/kg molybdenum or more in the tissue (*82*). This level is commonly accepted as the upper limit for safe feeding to cattle and is, therefore, proposed as the tolerance limit, even though levels of 0.001 to 0.002 mg/l molybdenum in river waters are not uncommon; and the Colorado River at Yuma, Ariz., is reported at 0.0069 (*44*).

An upper limit of 0.05 mg/l is proposed when the irrigation water is added to acid soils with a large capacity to combine with the element. The reason for this action is to protect against the possibility of inducing molybdenum toxicity at a later date as a result of overliming in humid and subhumid areas.

Nickel: Nickel toxicities occur in nature in conjunction with high levels of chromium in soils developed from serpentine rock. These soils may contain 400 to 5,000 mg/kg, compared with about 5 to 100 for most soils (*35*). Surprisingly, when the occurrence of serpentine-derived soils is considered, few results are available relating nickel toxicity to solution concentrations. Growth of flax is depressed by the presence of 0.5 mg/l nickel and this value is suggested here for a tentative tolerance limit. Examination of more sensitive crops may suggest a lower value.

Selenium: Tolerance limits for selenium should be based on animal toxicities, rather than those of plants. Plants containing 4 to 5 mg/kg selenium are commonly considered to induce toxic symptoms in animals. From results of Broyer (*28*), this level of selenium could result in many species from a level of 0.05 mg/l selenium in solution. Tolerance limits will, therefore, be placed at this value. The assumption is made that there will be sufficient management of irrigated lands so that selenium-accumulating plants will not be a factor. Fertilizer trials in greenhouse experiments indicate that the same limit might best be applied to water used on type 'b' lands as well.

Tin, Tungsten, and Titanium: Tin, tungsten, and titanium are effectively excluded by plants. The first two can undoubtedly be introduced to plants under conditions that will produce specific toxicities, but not enough is known about any of the three to prescribe tolerance limits at this time. Titanium is too insoluble to be of great concern. Tungsten has been observed to interfere with ascorbic acid metabolism in animals (*162*).

Vanadium: Vanadium toxicities have been induced in several plant species in concentrations in the neighborhood of 10 mg/l of the vanadate ion (*105*). Since this represents additions of about 100 pounds per acre of vanadium per year for 40 inches of irrigation, no increased level of vanadium for water use on type 'b' lands is proposed.

Zinc: Zinc has produced toxic symptoms in various plants in concentrations from 3 to 10 mg/l (*35, 105*). A tolerance limit of 5 mg/l is proposed here, since zinc is bound strongly to even coarse-textured soils. A limit of 10 mg/l is suggested even for water used on type 'b' land until evidence is presented to indicate that larger additions are acceptable. At irrigation additions of 40 inches per year, this would introduce about 100 pounds of zinc per acre per year.

Other Considerations

Acidity and alkalinity and common elements, including chlorides and bicarbonates, are discussed here only as they relate to irrigation water in general. Specific quality characteristics relating to arid region irrigation agriculture, or to water for supplemental irrigation in humid regions, will be discussed later. No attempt will be made to assign criteria to each, but appropriate guidelines and extent of importance will be described.

Acidity and Alkalinity in normal irrigation water, as measured by pH, have little direct significance. Since water itself is unbuffered, and the soil is a buffered system (except for extremely sandy soils low in organic matter), the pH of the soil will not be significantly affected by application of irrigation water. There are, however, some extremes and indirect effects.

Water having pH values below 4.8 applied to acid soils over a period of time may possibly render soluble iron, aluminum, or manganese in concentrations large enough to be toxic to plant growth. Similarly, addition of a neutral or acid irrigation water high in salts to an acid soil could result in a decrease in soil pH, thereby rendering these elements soluble. In some areas where acid mine drainage contaminates water sources, pH values as low as 1.8 have been reported. Waters having unusually low pH values such as this would be strongly suspect of containing toxic quantities of certain heavy metals or other elements.

Water having pH values in excess of 8.3 are highly alkaline and may contain high concentrations of sodium, carbonates, and bicarbonates. These constituents affect soils and plant growth directly or indirectly and these effects will be discussed later under specific ions.

Since most of the effects of acidity and alkalinity in irrigation waters are indirect as they relate to soils and plant growth, it is not practical to set narrow limits. Water having pH values in the range of 4.5 to 9.0 should not present any insurmountable problems assuming that no indirect limitations develop resulting from its use.

An imbalance of *common nutrient elements* can create an unfavorable environment for plant growth. Among the common ions which are essential for plant growth in relatively large quantities, there is a wide variation in their effect upon specific crops according to their total and relative concentrations. Essential ions such as calcium, magnesium, potassium, and sulfate may deter growth if the total or relative concentrations are out of balance. Plants vary in their tolerance of high concentrations of calcium in the soil solution. Masaewa (*103*) found that both calcium chloride and calcium nitrate were more toxic to soil cultures of flax than added sodium chloride. Wadleigh and Gauch (*184*), however, found some species such as guayule to be more tolerant of added calcium salts than of other neutral salts. Although harmful concentrations of calcium are rare, this illustrates a potentially unfavorable effect of one of the most beneficial ions. Magnesium is frequently more toxic than other elements at the same osmotic concentration and potassium may have effects similar to those of magnesium which may be alleviated by the presence of high calcium concentrations in the substrate. Sulfate has specific deleterious effects on many crops and has been found to limit calcium uptake. Sodium, which is very common in saline waters, affects irrigated crops in many ways. In addition to its effect on soil structure and permeability, sodium has been found by Lilleland, et al. (*90*) and Ayers (*8*) to be absorbed by plants and cause leaf burn in almonds, avocados, and in stone fruits grown in culture solutions. Bernstein (*16*) has indicated that water having SAR[1] values of 4 to 8 may injure sodium-sensitive plants. It is difficult to separate the specific toxic effects of sodium from the effect of absorbed sodium on soil structure. This latter factor will be discussed later. The complex interactions of the total and relative concentrations of these common ions upon various crops preclude their consideration as individual components for general irrigation use, except for sodium and possibly chlorides in areas where fruit would be important.

Chlorides are not generally phytotoxic to most crops. For this reason, no limits should be established because detrimental effects from salinity *per se* ordinarily deter crop growth first.

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[1] SAR: Sodium Adsorption Ratio $= \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$ expressed as me/*l*.

Certain fruit crops are, however, sensitive to chlorides. Bernstein (*16*) has indicated (table IV–17) that maximum permissible chloride contents in the soil solution range from 10 to 50 me/l for certain sensitive fruit crops. In terms of permissible chloride concentrations in irrigation water, values up to 20 me/l may be used, depending upon environmental conditions, crops, and irrigation management practices.

TABLE IV–17. Maximum Permissible Chloride Contents in Soil Solution for Various Fruit-Crop Varieties and Rootstocks (16)

Crop	Rootstock or variety	Limit of tolerance to chloride in soil solution me/l
	ROOTSTOCKS	
Citrus	Rangpur lime, Cleopatra mandarin	50
	Rough lemon, tangelo, sour orange	30
	Sweet orange, citrange	20
Stone fruit	Marianna	50
	Lovell, Shalil	20
	Yunnan	14
Avocado	West Indian	16
	Mexican	10
	VARIETIES	
Grape	Thompson seedless, Perlette	50
	Cardinal, Black Rose	20
Berries	Boysenberry	20
	Olallie blackberry	20
	Indian summer raspberry	10
Strawberry	Lassen	16
	Shasta	10

Foliar absorption of chlorides can be of importance in sprinkler irrigation (*48, 50*). The adverse effects vary between day and night (varying evaporative conditions) and the amount of evaporation that can occur between successive wettings; i.e., time after each pass with a slowly revolving sprinkler. There is less effect with nighttime sprinkling and less effect with fixed sprinklers (applying water at a rapid rate) as contrasted with slowly revolving sprinklers (required to apply water at a low rate). Concentrations as low as 3 me/l of chloride in the irrigation water have been found harmful when used on citrus, stone fruits, and almonds (*16*).

High Bicarbonate water may induce iron chlorosis by making the iron unavailable to plants (*26*). Problems have been noted with apples and pears (*134*) and with some ornamentals (*98*). Although concentrations of 10 to 20 me/l of bicarbonate will cause chlorosis in some plants, it is of little concern in the field where precipitation of calcium carbonate minimizes this hazard. It is difficult to set up specific criteria for such indirect effects.

Pesticides: Insecticides, fungicides, rodenticides, and herbicides, as a group, include both organic and inorganic compounds, all of which can directly or indirectly have a bearing upon the irrigation water in which they are found. The effects of some of these can be detrimental to crops, livestock, wildlife, and man. Some are easily broken down and disappear quickly while others are persistent. Some are only sparingly soluble in water, but all cause problems if accidental spillage produces high concentrations in water or if they become adsorbed on colloidal particles subsequently dispersed in water.

Compounds derived from petroleum are used directly for pest control or are involved in formulation and synthesizing other pesticides. Many of these substances produce no serious pollution hazards because they break down rapidly. Synthetic materials developed within the last 20 years produce most of the hazard potential. There are several types such as halogenated hydrocarbons, organophosphates, carbamates, phenoxys, thiocyanates, substituted ureas, and triazines. Many of the halogenated hydrocarbons appear to be quite persistent in the environment. Aldrin and dieldrin, chlorinated hydrocarbon insecticides, have been found to be absorbed by vegetable crops from contaminated soil. DDT, a widely used insecticide for many years, has been found to be very persistent and can be transported in runoff from agricultural areas as well as being transported by air currents (*193*).

Herbicides are used widely in agriculture directly on the crop and on the soil, on cropped and noncrop areas in the vicinity of agricultural areas, and for aquatic weed control. Petroleum solvents are effective aquatic weed killers which are rapidly dissipated and degraded. These aromatic solvents are widely used for keeping irrigation canals clear of weeds and are not harmful to crops (*29*). Copper sulfate is also widely used in irrigation for algae and other aquatic weed control. The copper concentration is maintained at a low level and has little or no history of producing harmful effects on crops. The fate of copper applied to [illegible]ed control in irrigation canals is being studied in cooperative aquatic weed research programs by the U.S. Bureau of Reclamation and Agricultural Research Service.

The phenoxy acid herbicides 2,4-D and 2,4,5-T have become suspect as contaminants of irrigation water. Some research has been initiated by various groups. These materials are known to be subject to rapid biological degradation in soils, but their fate in irrigation water and runoff water is still not well understood. Recent findings indicate that water temperature and dissolved oxygen content may influence the rate of biological decomposition of these herbicides in impounded water (*40*).

Millions of acres of farm, range, and forest lands are treated annually with millions of pounds of pesticides. It has been predicted that present use of pesticides will increase tenfold in the next 20 years. There is too little known about the ultimate fate of the many compounds and their influence on irrigated agriculture as well as the total environment. This stresses the need for further work to determine the potential effect of the many pesticides in irrigation water. Some work is currently underway by industry, universities, and Federal agencies to study the fate of these pesticides in irrigated agriculture; but as yet the state of science is very incomplete.

There is little evidence to indicate that under normal use insecticide contamination of irrigation water would be detrimental to plant growth or accumulate in or on plants in toxic concentrations. Herbicides, on the other hand, could be harmful to crop growth if misused. Since many herbicides break down in water, permissible limits should be established for the point of application to crops. Suggested permissible levels are shown in table IV–18 along with information on treatment rates of application and estimated concentrations in water reaching the field or crop. These levels are tentative and subject to change as indicated by future research.

Temperature: Excessively high or low temperatures in irrigation water can deter plant growth. It is not the temperature of the water *per se* that affects plant growth, but the resultant temperature of soil to which it is applied. Numerous investigations have been carried out relating the temperature of the substrate to plant growth; but few, regarding the direct effects of irrigation water temperature. Adverse soil temperature conditions can affect seedling emergence, growth rate, time of maturity, and yields of various crops. Here again, the effect on the plant is governed by specific soil characteristics and the genetic characteristics of specific plants. Furthermore, the temperature of the root zone and effects are governed by temperature changes occurring between irrigations.

In greenhouse studies with the Calora variety of rice, Raney (*138*) allowed the soil solution temperature to drop from 70 to 50 F for a period of 4 days. He found that if this were done in the stage between emergence and tillering, or 30 to 60 days after planting, the yield was depressed by approximately 10 percent. He also found a comparable critical period during the flowering period, about 100 days after planting.

Other water temperature effects were noted by Wieringa (*194*) on kidney beans. In greenhouse experiments, he found that yields would increase with soil temperature increasing from 70 to 86 F. With temperatures of 50 F, no germination occurred. By decreasing the temperature from 77 to 50 F for a period of 3 days, a 17-percent decrease in root and foliar growth occurred if the temperature decrease was made at the three-leaf stage. The same process produced a 40-percent decrease in root and foliar growth at the six-leaf stage and the yield itself decreased 15 percent when the process was carried out at the nine-leaf stage.

In regard to tomatoes, Martin and Wilcox (*102*) in greenhouse studies found minimum temperatures for satisfactory growth at 56 to 58 F. Increasing temperatures produced increased yields.

Holekamp and others (*69*) studied the effects of water temperatures upon cotton in the greenhouse. For emergence, best results were obtained in the 60 to 70 F range. With temperatures less than 60 F average minimum soil temperature, only 40 percent of the plantings produced seedlings. They concluded that there was a 1.7-percent decrease in percentage of emergence for each degree less than the 60 F average minimum.

The adverse effects of cold water on the growth of rice were suddenly brought to the attention of rice growers when cold water was first released from Shasta Reservoir in California (*138*). Summer water temperatures were suddenly dropped from about 61 F down to 45 F. Research is still proceeding and some of the available information was recently reviewed by Raney and Mihara (*140*). Dams such as the Oroville Dam are now being planned so that water can be withdrawn from any reservoir depth to avoid the cold-water problem. Warming basins have been used (*139*). There are opportunities in future planning to separate waters—the warm waters for recreation and agriculture; the cold waters for cold-water fish, salmon spawning, etc.

Review of research accomplishments does not offer guidelines for establishing temperature criteria for irrigation waters. Aside from the other complicating variables previously mentioned, the manner in which irrigation water is applied, surface or sprinkler, could influence changes in the resultant soil temperature. Assuming that the soil

TABLE IV–18. Levels of Herbicides in Irrigation Waters [1]

Herbicide	Site of use	Type of formulation	Treatment rate	Likely concentration in irrigation water reaching crop or field	Crop injury threshold in irrigation water (mg/l) [2]	Remarks
Acrolein	In water from cylinders under nitrogen gas pressure.	Soluble liquid	15 mg/l X 4 hours.	10 to 0.1 mg/l	**Flood or furrow:** beans-60, corn-60, cotton-80, soybeans-20, sugar beets-60.	Canals up to 200 cfs concentration reduced to minimum in 10 to 20 miles.
			0.6 mg/l X 8 hours.	0.4 to 0.02 mg/l	**Sprinkler:** corn-60, soybeans-15, sugar beets-15.	Canals, 200 to 500 cfs concentration reduced to minimum in 20 to 30 miles.
			0.1 mg/l X 48 hours.	0.05 to 0.1 mg/l		Canals 1,000 cfs and larger concentration to minimum in 30 to 50 miles.
Aromatic solvents (xylene).	Emulsified in flowing water.	Emulsifiable liquid.	6–10 gal/cfs in 30–60 minimum (300–750 mg/l).	700 mg/l or less	Alfalfa->1,600, beans-1,200, carrots-1,600, corn-3,000-cotton-1,600, grain sorghum->800, oats-2,400, potatoes-1,300, wheat->1,200.	Concentration reduced rapidly from point of application within 2 to 6 miles and almost completely in 6 to 10 miles.
Copper sulfate	In flowing water canals or in reservoirs.	Coarse pentahydrate crystals.	0.5 to 3.0 mg/l (continuous).	0.8 to 0.04 mg/l in 10 miles.	Apparently above concentrations used for weed control.	
			1/3 to 1 lb/cfs (slug).	9.0 to 0.08 mg/l in 10 to 20 miles.		Concentration reduced more rapidly with distance from slug applications.
Amitrole-T	On bank weeds along irrigation canals and on cattail in drain canals.	Foliage spray	6 to 16 lb/A	Usually less than 0.1 mg/l.[a]	Beets (Rutabaga)->3.5, corn->3.5.	Registered for use only in drain canals and marshes, but actually used for control of bank weeds along western irrigation canals.
Dalapon	do	Foliage	15 to 30 lb/A	Usually less than 0.5 mg/l.[a]	Beets->7.0, corn-<0.35.	Same as amitrole-T.
Diquat	In water or over surface of canals and reservoirs.	Liquid	3–5 mg/l or 1–1.5 lb/A.	Usually less than 0.1 mg/l.	Beans-5.0, corn-125.0	Diquat used in Florida for control of submersed weeds and floating weeds. **Do not use for 10 days.** Not used in western irrigation systems.
Diuron	On bottoms and banks of small canals when no water is in canal.	Wettable powder suspension sprayed.	64 lb/A	Below crop injury threshold.	No data	Used mostly in small farm ditches with intermittent water flow.

Monuron	Same as for diuron	Same as for diuron.	64 lb/A	do	do	Same as for diuron except first water through canal after treatment not used for irrigation.
Endothall Na and K salts.	In ponds and reservoirs mostly in Eastern States.	Liquid or granule.	1–4 mg/l	Probably little or none after waiting period.	Corn-25, field beans-1.0, alfalfa->10.0.	Must wait 7 days after treatment before using water for irrigation or domestic purposes.
Dimethylamines	In water control canals in Florida. Promising use in western canals.	Liquid	0.5–2.5 mg/l	Same as for Na and K salts.	Corn->25, soybeans->25, sugar beets-25.	Wait for 7 to 25 days (depending on concentration) after treatment before using water.
2,4-D	Weeds along canal banks.	Liquid spray	1 to 4 lb/A usually as amine.	3.0 to 1.0 μg/l, 2 to 10 miles below treatment.	Field beans->3.5, <10. Grapes-0.7–1.5.	**Registered precaution:** Do not contaminate water to be used for irrigation.
	Floating and emersed weeds in southern canals.	do	do	0.1 mg/l or less to none in 3 weeks.	Sugar beets-3.5	A minimum waiting period of 3 weeks before using treated water for irrigation.
Silvex	Phreatophytes on floodways, along canals, reservoirs, and streams.	Liquid spray as ester.	2 to 4 lb/A	No data. Probably less than 0.1 mg/l.	No data	Silvex registered only for control of aquatic weeds in nonflowing water at 4 lb/100 gallons of water. Do not use in water to be used for agricultural or domestic purposes.
	Floating and emersed weeds in southern waterways	Liquid spray over surface.	2 to 8 lb/A	From 10 to 1,600 μg/l, 1 day after application. 1 to 70 μg/l, 5 weeks after treatment.	do	
Dichlobenil	Promising bottom treatments in canals without water.	Granules or wettable powder spray.	7 to 10 lb/A		Alfalfa-10, corn->10, soybeans-1.0, sugar beets-1.0 to 10.	Registered for control of submersed weeds in lakes, ponds, and drainage ditches where water not used for agricultural or domestic purposes.
Fenac	Same as dichlobenil	Same as dichlobenil.	10 to 20 lb/A	0.66 to 1.8 mg/l below treated area. 0.007 to 0.100 mg/l 2 hours later.	Alfalfa-1.0, corn-10, soybeans-0.1, sugar beets-0.1 to 10.	Same as dichlobenil.
Pichloram	For control of brush and weeds on watershed areas.	Liquid spray or granules.	1 to 3 lb/A	No data	Corn->10, field beans-0.1, sugar beets-<1.0.	Gives excellent control of Canada thistle and other bank weeds, but use near canals hazardous.

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[1] Data submitted by F. L. Timmons, Crops Protection Branch, Crops Research Division, ARS, USDA (unpublished).

[2] Data are for flood or furrow irrigation for all herbicides except when sprinkler irrigation is indicated for acrolein. Threshold of injury is lowest concentration that caused either temporary or permanent injury. Often this concentration did not cause final reduction in crop yield or quality.

[3] Estimates based upon very limited data and extensive observations.

temperature would not be lowered beyond that of a cold irrigation water, nor raised above that of a warm irrigation water, a desirable range of temperatures would be from 55 to 85 F.

Effect on plant quality

There are certain water quality considerations which are not directly concerned with plant growth *per se*. They are significant, however, in that they adversely affect the quality of the plant for its intended use. For example, water may carry microorganisms either directly pathogenic to the plant, or to animals or humans consuming these plants. Water may contain a material which is not toxic to plant growth, but may be absorbed by and accumulate in plants at levels which may be toxic to animals or humans which consume them. Finally, there are materials such as sediment which affect the appearance and, hence, the marketability of the crop.

Microorganisms, Pathogenic to Plants, Animals or Humans

In general, the danger of spread of *plant pathogens* in irrigation water is so slight that it is usually ignored. Some plant pathogens, however, can survive and be transported in irrigation water. In irrigated areas where runoff water from infected cultivated fields is used again downstream for irrigation, there is definite probability that disease organisms will be spread from one field to another. The importance of this is uncertain compared to other means of spread such as dust storms, farm-to-farm movement of farm equipment, or direct wind transport of spores.

Faulkner and Bolander (*54*) confirm that large numbers of nematodes, including plant parasites, are transported in irrigation water. No attempt has been made to ascertain the economic importance of nematodes distributed by water. However, there is little doubt that irrigation water could be a significant source of nematode infestations. Data indicate that each time an acre of land in the Lower Yakima Valley is irrigated, it may receive from approximately 4 million to over 10 million plant parasitic nematodes.

The most likely situation to cause trouble is where the contaminated water is used for overhead sprinkling. Some bacterial diseases, and diseases caused by the so-called watermold group of fungi, may be increased by this practice. Root disease organisms in general can probably be introduced into clean soils this way also. Recommendations have been made in the tobacco growing areas, where the wildfire disease is a problem, that drainage water from infected tobacco fields not be used to irrigate other fields. Also, fruit growers are advised to avoid using drainage water for sprinkler irrigation in orchards (109).

Lack of efforts to control or eliminate plant disease organisms in irrigation water is partly due to the difficulty of doing anything effective about them. Usually, any plant disease control based on sanitation is limited to the easiest or least expensive procedures because, at best, they are only a partial answer. The disease organisms are microscopic and cannot be screened from water like weed seeds. Chemical treatment of the water is expensive and has many undesirable consequences.

Water may be assayed for plant pathogens; but there are thousands, or perhaps millions of harmless microorganisms for every one that causes a plant disease. While such selective bioassays are valuable in research, they are not practical for monitoring.

If plant disease organisms are to be included in water quality criteria, they should be framed in terms of preventive measures rather than by any assay procedure. For example, dumping of plant material, which could be diseased, into lakes, streams, or irrigation systems should be prohibited. Water used in washing of fresh produce, such as potatoes, may have to be treated before return to water supplies that will be used to irrigate crops. It is also desirable to prevent storage of irrigation water in a quarantined area for downstream use. Pests such as the soybean cyst nematode or other plant nematodes could easily be spread in this way.

Plant infection is not considered serious unless an economically important percentage of the crop is affected. The real danger is that a trace of plant disease can be spread by water to an uninfected area where it can then spread by other means and become important. It is unlikely that any method of water examination would be as effective in preventing this as would be prohibitions such as those suggested above.

Many *microorganisms, pathogenic for either animals or humans*, or both, may be carried in irrigation water, particularly that derived from surface sources. The list comprises a large variety of bacteria, spirochetes, protozoa, helminths, and viruses, which find their way into the irrigation water from municipal and industrial wastes, including food-processing plants, slaughterhouses, poultry-processing operations, and feedlots. The diseases associated with these organisms include bacillary and amebic dysentery, Salmonella gastroenteritis, typhoid and paratyphoid fevers, leptospirosis, cholera, vibriosis, and infectious hepatitis. Other infections less commonly seen, at least in the United States, are tuberculosis, brucellosis, listeriosis, coccidiosis, swine erysipelas, ascariasis, cysticercosis and tapeworm disease, fascioliasis, and schistosomiasis. Isolation of the pathogens themselves is far too slow and costly to consider other than for research purposes and correlation.

Of the types of irrigation commonly practiced, sprinkling undoubtedly requires the best quality of water from a microbiological point of view, as the water and organisms are frequently applied directly to that portion of the plant above the ground, and especially for fruits and leafy crops such as strawberries, lettuce, cabbage, alfalfa, clover, etc., which may be consumed raw. Flooding the field may pose the same microbiological problems if the crop is eaten without thorough cooking. Subirrigation and furrow irrigation present fewer problems as the water rarely reaches the upper portions of the plant; and root crops, as well as normal leafy crops and fruits, ordinarily do not permit penetration of the animal and human pathogens to the inside of the plant. Criteria for these latter types may also depend upon the characteristics of the soil, climate, and other variables which affect the survival of the microorganisms.

Benefits can be obtained by coordinated operation of reservoir releases with downstream inflows to provide sedimentation and dilution factors to reduce markedly the concentrations of pathogens in the water applied in irrigation (*31, 84*).

Tanner (*163*) and Rudolfs, Falk, and Ragotzkie (*146*) have reviewed the literature on the occurrence and survival of pathogenic and nonpathogenic enteric bacteria in soil, water, sewage, and sludges, and on vegetation irrigated or fertilized with these materials. It would appear from these reviews that fruits and vegetables growing in infected soil can become contaminated with pathogenic bacteria and that these bacteria may survive for periods of a few days to several weeks or more in the soil and on vegetation.

Falk (*53*) and Rudolfs, Falk, and Ragotzkie (*144*) studied the relative incidence of coliform organisms on tomatoes grown on three plots of ground: one plot irrigated with settled sewage concurrently with growth, one irrigated previous to planting but not further, and one with no previous or concurrent irrigation. Except for the tomatoes wth abnormal stem ends, there was no material difference in coliform counts per gram of tomatoes from the three plots. These same authors further found that *Salmonella cerro* and *Shigella alkalescens* organisms sprayed on growing tomatoes disappeared within 2 to 7 days, whereas organisms of the coliform group remained for considerably longer periods.

Norman and Kabler (*121*) made coliform and other bacterial counts in samples of sewage-contaminated river and ditch waters and of soil and vegetable samples in the fields to which these waters were applied. They found that although the bacterial contents of both river and ditch waters were very high, both soil and vegetable washings had much lower counts. For example, where irrigation water had coliform counts of 230,000/100 ml, leafy vegetables had counts of 39,000/100 grams and smooth vegetables, such as tomatoes and peppers, only 1,000/100 grams. High enterococcus counts accompanied high coliform counts in water samples, but enterococcus counts did not appear to be correlated in any way with coliform counts in soil and vegetable washings.

Dunlop and Wang (*43*) have also endeavored to study the problem under actual field conditions in Colorado. *Salmonella, Ascaris* ova and *Entamoeba coli* cysts were recovered from more than 50 percent of irrigation water samples contaminated with either raw sewage or primary-treated, chlorinated effluents. Only one of 97 samples of vegetables irrigated with this water yielded *Salmonella*, but *Ascaris* ova were recovered from two of 34 of the vegetable samples. Although cysts of the human pathogen, *Entamoeba histolytica*, were not recovered in this work, probably due to a low carrier rate in Colorado, their similar resistance to the environment would suggest that these organisms would also survive in irrigation water for a considerable period of time. It should be pointed out, however, that this work was done entirely with furrow irrigation on a sandy soil in a semiarid region, and the low recoveries from vegetables cannot necessarily be applied to other regions or to sprinkler irrigation of similar crops. In fact, Müller (*116*) has reported that two places near Hamburg, Germany, where sprinkler irrigation was used, *Salmonella* organisms were isolated 40 days after sprinkling on soil and on potatoes, 10 days on carrots, and 5 days on cabbage and gooseberries.

Müller (*117*) has also reported that 69 of 204 grass samples receiving raw sewage by sprinkling were positive for organisms of the typhoid-paratyphoid group (*Salmonella*). The bacteria began to die off 3 weeks after sewage application; but 6 weeks after application, 5 percent of the samples were still infected. These findings emphasize the importance of having good quality water for sprinkler irrigation.

Tubercle bacilli have apparently not been looked for on irrigated crops in the United States. However, Sepp (*154*) states that several investigations on tuberculosis infection of cattle pasturing on sewage-irrigated land have been carried out in Germany. The investigators are in general agreement that if sewage application is stopped 14 days before pasturing, there is no danger that the cattle will contract bovine tuberculosis through grazing. In contrast, Dedie (*39*) has reported that these organisms can remain infective for 3 months in waste waters, and up to 6 months in soil. The recent findings of atypical mycobacteria in intestinal lesions of cattle with concurrent tuberculin sensitivity in the United States may possibly be due to ingestion of these organisms either from soil or irrigated pastures.

Both animals and human beings are subject to helminth infections—ascariasis, fascioliasis, cysticercosis and tapeworm infection, and schistosomiasis—all of which may be transmitted through surface irrigation water and plants infected with the ova or intermediate forms of the organisms. The ova and parasitic worms are quite resistant to sewage treatment processes (*187*) as well as to chlorination (*22*) and have been studied quite extensively in the application of sewage and irrigation water to various crops (*125, 153, 187*).

The common liver fluke, *Fasciola hepatica*, the ova of which are spread from the feces of many animals, affects cattle and sheep (*2, 169, 171*) commonly, in the United States, and man to a lesser extent. The intermediate hosts, certain species of snails, live in springs, slow-moving swampy waters, and on the banks of ponds, streams, and irrigation ditches. After development in the snail, the cercarial forms emerge and encyst on grasses, plants, bark, or soil. Cattle and sheep become infected by ingestion of the grasses and plants, or the water, in damp or irrigated pastures where vegetation is infested with metacercariae. Man contracts the disease by ingesting plants such as watercress or lettuce containing the encysted metacercariae.

Ascaris ova are also spread from the feces of infected animals and man and are found in irrigation water (*187*). Cattle and hogs are commonly infected, where the adult worms mature in the intestinal tract, sometimes blocking the bile ducts. Ascaris ova have been reported to survive for 2 years in irrigated soil and have been found on irrigated vegetables even when chlorinated effluent was used for irrigation (*61, 145*).

Schistosomiasis, although not yet prevalent in the United States except in immigrants from endemic areas, should be considered for the future as these individuals move about the country into irrigated areas. The life cycle of these schistosomes is similar to that of the liver fluke in that eggs from the feces or urine of infected individuals are spread from domestic wastes and may reach surface irrigation waters where the miracidial forms enter certain snails and multiply, releasing fork-tailed cercariae. Although these cercariae may produce disease in man if ingested, the more common method of infection is through the skin of individuals working in the infested streams and irrigation ditches. Such infections are most common in Egypt (*10*) and other irrigated areas where workers wade in the water without boots. It is unlikely that the cercariae would survive long on plants after harvest.

Little is known of the possibility that enteric viruses such as polioviruses, Coxsackie, ECHO, and infectious hepatitis viruses may be spread through irrigation practices. Murphy and his coworkers (*118*) tested the survival of polioviruses in the root environment of tomato and pea plants in modified hydroponic culture. In a second paper, Murphy and Syverton (*119*) studied the recovery and distribution of a variety of viruses in growing plants. The authors conclude that it is unlikely that plants or plant fruits serve as a reservoir and/or carrier of poliovirus. However, their findings of significant absorption of a mammalian virus in the roots of the plants suggest that more research is needed in this area.

Many other microorganisms than those specifically mentioned in this section may be transmitted to plants, animals, and human beings through irrigation practices. One of the more serious of these is vibriosis. In some cases, definitive information on other microorganisms is lacking. In others, such as the cholera organisms, while their significance in other parts of the world is well established, they are no longer important in the United States.

Direct search for the presence of pathogenic microorganisms in streams, reservoirs, irrigation water, or on irrigated plants is too slow and cumbersome for routine control or assessment of quality. Instead, accepted index organisms such as the coliform group and fecal coli (*74*), which are usually far more numerous from these sources, and other biological or chemical tests, are used to assess the quality of the water.[1] Two extensive investigations of stream basins (*178, 180*) have demonstrated the value of these criteria in assessing the quality of raw water. Maintenance of quality within these recommendations should insure sufficiently low concentrations of pathogenic microorganisms that no hazard to animals or man should result from the use of the water on even those crops which are consumed raw.

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[1] For a more complete discussion, see Geldreich, E. E. 1966. Sanitary significance of fecal coliforms in the environment. U.S. Department of the Interior. FWPCA. Pub. WP-20-3.

In the study of the Red River of the North, North Dakota-Minnesota (*178*), Salmonella were not recovered from a reference point upstream from the Fargo and Moorhead municipal treatment plants and from a sugar company plant at Moorhead. Total and fecal coliforms at this upstream reference point were 500/100 ml and 100/100 ml, respectively. Salmonella were recovered in the three sources of waste and in the river below the discharges, the river samples showing 75,000 coliforms/100 ml and 15,500 fecal coli/100 ml. It is suggested in that report that the stream should be maintained at not more than 5,000 coliforms/100 ml even at critical periods of riverflow. Such a standard could be maintained by secondary treatment plus disinfection of the waste sources.

In a similar, but more extensive, study of the South Platte River Basin in Colorado (*180*), Salmonella recoveries have not yet been reported, but maximum total coliforms of 5,000/100 ml and maximum fecal coli of 1,000/100 ml were recommended. In this study also, attention was given to dissolved oxygen (DO) and 5-day, 20 C BOD levels. Minimum levels of 4 mg/l DO and a maximum of 20 mg/l, 5-day 20 C BOD levels were also recommended for water used primarily for irrigation. These criteria likewise are consistent with quality that can be maintained by secondary treatment plus disinfection of all waste sources.

Toxicity to Animals or Humans Through Accumulation in Plants

Selenium is an example of an element which may occur in soils in trace amounts, yet which may be accumulated in certain cereals and pasture plants without apparent injury, but in quantities harmful to animals or humans when consumed. Deficiencies of this element in animal diets may result in white muscle disease, but an excess produces conditions known as "alkali disease" and "blind staggers." Trelease and Beath (*167*) have noted that selenium absorbed by grasses and cereals enter the food chain of animals and humans. Molybdenum is another example of an element which can accumulate in plants and become detrimental to livestock.

There is no evidence to date to indicate that selenium or molybdenum occurrence in natural irrigation water is a significant factor. It is important to point out, however, that pollution of irrigation waters by industrial sources could introduce harmful concentrations of these and other elements.

Suspended Solids: Suspended solids in irrigation water can affect plant growth and quality in several ways. Deposition of colloidal particles on the soil surface can produce crusts which inhibit water infiltration and seedling emergence. This same deposition and crusting can reduce soil aeration to a level where it impedes plant development. High colloidal content in water used for sprinkler irrigation could result in deposition of films on leaf surfaces which could reduce photosynthetic activity and thereby deter growth. Where sprinkler irrigation is used for leafy vegetable crops such as lettuce, sediment may accumulate on the growing plant, affecting the marketability of these products.

Radionuclides: There are no generally accepted standards for control of radioactive contamination in irrigation water. For most radionuclides, the use of USPHS Drinking Water Standards (*175*) appear to be reasonable for irrigation water. Supplies containing not in excess of 3 and 10 pc/l, respectively for radium-226 and strontium-90 would be acceptable without consideration of other radioactive sources. In the known absence of strontium-90 and alpha-emitting radionuclides, the water supply is considered acceptable if the gross beta activity does not exceed 1,000 pc/l. If the gross beta activity is in excess of this amount, a more complete radiochemical analysis is required to determine that the sources of radiation exposure are within the limits of the Radiation Protection Guides. One state, Washington, has proposed such a standard for irrigation water (*188*).

The limiting factor for radioactive contamination in irrigation is its transfer to foods and eventual intake by humans. Such a level of contamination would be reached long before any damage to plants themselves could be observed. Plants can absorb radionuclides in irrigation water in two ways: direct contamination of foliage through sprinkler irrigation, and indirectly through soil contamination. The latter presents many complex problems since eventual concentration in the soil will depend on the rate of water application, the rate of radioactive decay, and other losses of the radionuclide from the soil. Some studies relating to these factors have been reported (*96, 107, 108, 112, 114, 127*).

Calculations, using the drinking water standards listed above, indicate that irrigation water having the maximum permissable concentrations of strontium-90 and radium-226 would be permissible for at least nine and 40 years, respectively, before detrimental effects would be noted.

Impairment of soil quality

Sodium Hazard

Sodium in irrigation water may become a problem in the soil solution as a component of total salinity increasing the osmotic concentration, and as a specific source of injury to fruits. It is mainly a problem, however, due to its effect on soil structure, infiltration, and permeability rates. Since good drainage is essential for management of salinity in irrigation, and for reclamation of saline lands, good soil structure and permeability must be maintained. A high percentage of exchangeable sodium in a soil containing swelling-type clays results in a dispersed condition unfavorable for water movement and plant growth.

The organic and clay fractions of the soil possess ion exchange properties. These fractions carry predominantly negative charges and, therefore, absorb positive ions (cations); predominantly calcium, magnesium, potassium, sodium, hydrogen, and aluminum. The distribution of adsorbed cations in the soil is in equilibrium with the soil solution. Anything that alters the composition of the soil solution, such as irrigation or fertilization, disturbs the equilibrium and alters the distribution of adsorbed ions in the soil. When calcium is the predominant cation adsorbed on this exchange complex, the soil tends to have a granular structure which is easily worked and readily permeable. When the amount of adsorbed sodium exceeds 10 to 15 percent of the total cations on the exchange complex, the clay becomes dispersed and slowly permeable unless a flocculated condition is maintained due to a high concentration of total salts. Where soils have a high exchangeable sodium content and are flocculated due to the presence of free salts in solution, subsequent removal of salts by leaching will cause sodium dispersal to occur unless leaching is accomplished using additions of calcium or calcium-producing amendments.

Adsorption of sodium from a given irrigation water is a function of the proportion of sodium to divalent cations (calcium and magnesium) in that water. To estimate the degree to which sodium will be adsorbed by a soil from a given water when brought into equilibrium with it, the U.S. Salinity Laboratory (*181*) proposed the sodium adsorption ratio (SAR); see footnote, page 155. As soils tend to dry, the SAR value of the soil solution increases even though the relative concentrations of the cations remain the same. This is apparent from the above equation where the denominator is a square-root function. This is a significant factor in estimating sodium effects on soils.

The SAR value can be related to the amount of exchangeable sodium in the soil expressed as a percentage of the total exchangeable cation content. This latter value is called the exchangeable sodium percentage (ESP). From empirical determinations, the U.S. Salinity Laboratory obtained an equation for predicting a soil ESP value based on the SAR value of a water in equilibrium with it. This is expressed as follows:

$$\mathrm{ESP} = \frac{100\,[a+b(\mathrm{SAR})]}{1+[a+b(\mathrm{SAR})]}$$

The constants "a" (intercept representing experimental error) and "b" (slope of the regression line) were determined statistically by various investigators who found "a" to be in the order of −0.06 to 0.01 and "b" to be within the range of 0.014 to 0.016. Thus, ESP as calculated from SAR value will normally have a value slightly higher than the SAR. This relationship is shown in the nomogram [fig. IV–4 developed by the U.S. Salinity Laboratory (*181*)]. For sensitive fruits, the tolerance limit for SAR of irrigation water is about 4. For general crops, a limit of 8 to 18 is generally considered within a usable range although this depends to some degree on the type of clay mineral, electrolyte concentration in the water, and other variables.

The ESP value that significantly affects soil properties varies according to the proportion of swelling and nonswelling clay minerals. An ESP of 10 to 15 percent is considered excessive if a high percentage of swelling clay minerals such as montmorillonite is present. Fair crop growth of alfalfa, cotton, and even olives, have been observed in soils of the San Joaquin Valley with ESP values ranging from 60 to 70 percent (*148*). This condition is being studied further and is apparently the result of a high percentage of nonswelling clay minerals.

Prediction of the equilibrium ESP from SAR values of irrigation waters is complicated by the fact that the salt content of irrigation water becomes more concentrated in the soil solution. According to the Salinity Laboratory (*181*), shallow ground waters 10 times as saline as the irrigation waters may be found at depths of 10 feet and a salt concentration two to three times that of irrigation water may be reasonably expected in the first-foot

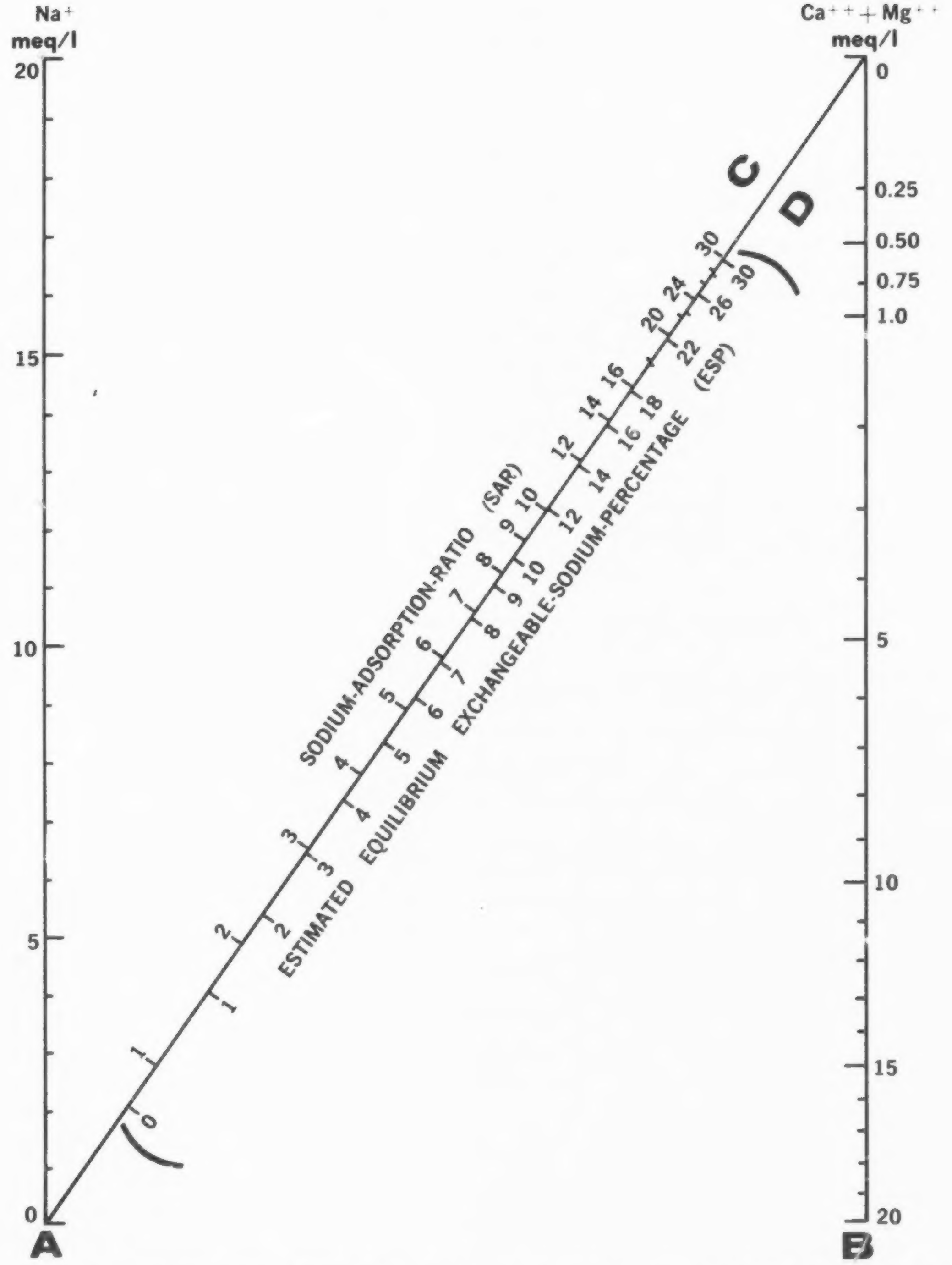
Na+ meq/l
Ca++ + Mg++ meq/l
20
15
10
5
0
0
0.25
0.50
0.75
1.0
5
10
15
20
A
B
C
D
SODIUM-ADSORPTION-RATIO (SAR)
ESTIMATED EQUILIBRIUM EXCHANGEABLE-SODIUM-PERCENTAGE (ESP)
0
1
2
3
4
5
6
7
8
9
10
12
14
16
20
24
30
1
2
3
4
5
6
7
8
9
10
12
14
16
18
22
26
30

Figure IV-4—Nomogram for determining the SAR value of irrigation water and for estimating the corresponding ESP value of a soil that is at equilibrium with the water (181)

depth. Under conditions where precipitation of salts and rainfall may be neglected, the salt content of irrigation water will increase to higher concentrations in the soil solution without change in relative composition. The SAR increases in proportion to the square root of the concentration; therefore, the SAR applicable for calculating equilibrium ESP in the upper root zone may be assumed to be two to three times that of the irrigation water.

Many attempts have been made to predict cation exchange reactions in soils (*45, 51, 80, 181*). Some of these have been used to predict the degree to which sodium will be adsorbed by a soil from a water of given quality. Many variables can influence the cation equilibria attained in the soil. These include the relative proportions of cations and anions in the water added and those present in the soil, the presence of slightly soluble constituents such as lime and gypsum, clay mineral types present, and the salt concentrating action of evapotranspiration. For this reason, field studies are needed to support predictive relations developed under laboratory conditions.

BOD and Soil Aeration

The need for adequate available oxygen in the soil for optimum plant growth is well recognized. To meet the oxygen requirement of the plant, soil structure (porosity) and soil water contents must be adequate to permit good aeration. Conditions that develop immediately following irrigation are not clearly understood.

Soil aeration and oxygen availability normally present no problem on well-structured soils with good quality water. Where drainage is poor, oxygen may become limiting. Utilization of waters having high BOD or COD values could aggravate the condition by further depleting available oxygen and produce reducing conditions in the soil. Aside from detrimental effects of oxygen deficiency for plant growth, reduction of elements such as iron and manganese to the more soluble divalent forms may create toxic conditions. Other biological and chemical equilibria may also be affected.

There is very little information regarding the effect of using irrigation waters with high BOD values on plant growth. Between source of contamination and point of irrigation, considerable reduction in BOD value may result. Sprinkler irrigation may further reduce the BOD value of water. Infiltration into well-drained soils can also decrease the BOD value of the water without seriously depleting the oxygen available for plant growth.

Where irrigation is used for disposal of waste effluents with high BOD, lack of oxygen and reducing conditions could easily become significant factors for plant growth. However, if amounts of water applied do not greatly exceed crop requirements, it is probable the crop will not be adversely affected.

Suspended Solids

Large quantities of suspended solids in irrigation water can affect irrigation in many ways. In surface irrigation, suspended solids can interfere with the flow of water in conveyance systems and structures. Deposition of sediment not only reduces the capacity of these systems to carry and distribute water, but can also decrease reservoir storage capacity. For sprinkler irrigation, suspended mineral solids may cause undue wear on irrigation pumps and sprinkler nozzles as well as possibly plugging up the latter, thereby reducing irrigation efficiency.

Soils are specifically affected by deposition of these suspended solids, especially when they consist primarily of clays or colloidal material. These cause crust formations which reduce seedling emergence. In addition, these crusts reduce infiltration thereby reducing irrigation efficiency and hindering the leaching of saline soils. The scouring action of sediment in streams has also been found to affect soils adversely by contributing to the dissolution and increase of salts in some areas (*139*).

Conversely, sediment high in silt may improve the texture, consistence, and water-holding capacity of a sandy soil. An example of this beneficial effect has occurred by irrigation from the silt-laden waters of the Virgin River in Southwestern Utah, where silt loams have been deposited over loamy sands to depths of 1 foot or more over a period of many years.

specific irrigation water quality considerations for arid and semiarid regions

Environmental factors

Climate

Climatic variability exists in arid and semiarid regions. In the Far West, the Pacific Ocean provides considerable moderation, preventing extremely high summer temperatures and extremely low winter temperatures; this influence decreases with distance from the coast and with the presence or absence of intervening mountains. There are differences due to altitude, the highest elevations having the shortest frost-free growing season, and the lowest elevations having the longest. The latitude affects the length of the growing seasons, permitting subtropical fruits and winter vegetables, etc., to be grown in the low-elevation southern portions. Deciduous fruits with a winter chilling requirement are examples of crops favoring the northern latitudes. There can be heavy winter precipitation, generally increasing from south to north, and increasing with elevation. Summer showers are common, increasing north and east from California. The only thing common through this Western part of the country is the inadequacy of precipitation during the growing season. In most areas of the West, intensive agriculture is not possible without irrigation. Irrigation must supply one-half to all or most of the soil moisture required for crops for annual periods ranging from 3 to 12 months.

Annual precipitation varies in the Western United States from practically zero in the southwestern deserts to in excess of 100 inches in the upper western slope of the Pacific Northwest. The distribution of precipitation throughout the year also varies, with no rainfall during extended periods in many locales. Often the rainfall occurs during nongrowing seasons.

The amount of precipitation and its distribution is one of the principal variables in determining the diversion requirement, or "demand," for irrigation water.

Land

Soils of the arid and semiarid regions were developed under a drier regime than the soils of the more humid areas. They have more weatherable minerals and consequently are generally better supplied with the nutrient elements except for nitrogen. These soils generally have relatively high exchangeable cation status, base status, and a low degree of acidity. Also, if they have developed profiles, the topsoils are not as deep as in the more humid areas. Because of less frequent passage of rainfall through the soil profiles, they are shallower and are more apt to be saline.

For irrigation purposes, soils are sometimes grouped in accord with their topographic position. Upland soils are those formed in place by the weathering of the underlying parent material or to some extent, from materials moved laterally by colluvial forces. They are also the soils where the greatest erosion is usually taking place. Most of the material eroded and transported downstream as sediments, largely during floods, is deposited on the flood plain and deltas. The deep, medium-textured soils of the flood plains are recognized as the prime agricultural soils. Farther down the river system, soils of the basin are normally found. These basins are regions of flat gradient where drainage is impeded. They may be swampy, at least during time of flood, but can be a filled lake or estuary. The distinctive features are a high water table and fine-textured materials.

One other soil position should be mentioned—the terrace. The terrace is created as a flood-plain alluvium. Because of stream lowering, there is no longer deposition, but its gradient is flat enough to limit erosion hazard. Over thousands of years, the soil can develop a profile. Percolating water causes the leaching of colloidal material and soluble constituents from the top soil to be deposited or precipitated out in the subsoil. The subsoil constitutes a horizon below the surface and usually is of finer texture and more compact. The surface horizon varies in thickness from a few inches to a few feet and can provide a good environment for plant roots if deep enough; but the subsoil often cannot, and water often does not penetrate it readily. Soils with restrictive horizons are not the best for irrigated agriculture; but if in an elevated position relative to surrounding land, the night air currents may make them more frost-free and suitable for sensitive crops that cannot be grown elsewhere.

Water

Each river system within the arid and semiarid portion of the United States has quality characteristics peculiar to its geologic origin and climatic environment. In considering water quality characteristics as related to irrigation, both historic and current data for the stream and location in question should be used with care because of the large seasonal and sporadic variations which occur.

Both chemical composition and sediment load in surface waters will vary with the stage of flow. Salt concentration during low-flow periods is usually greater than during peak flows. Storm runoff not only affects the salt content, but frequently tends to increase the sediment burden. Because of variations in rainfall distribution, water quality characteristics will differ significantly. Where rainfall is more uniformly distributed, the maximum concentrations of dissolved solids are two to three times the minimum, whereas this factor may vary from 5 to 10 where rainfall distribution is more sporadic.

The range of sediment concentrations of a river throughout the year usually is much greater than the range of dissolved solids concentrations. Maximum concentrations may be 10 to more than a thousand times the minimum concentrations. Usually the sediment concentrations are higher during high flow than during low flow. This differs inversely from dissolved-solids concentration which is usually lower during high flows.

Four general designations of water have been used (*136*), based on their chemical composition: calcium-magnesium, carbonate-bicarbonate; calcium-magnesium, sulfate-chloride; sodium-potassium, carbonate-bicarbonate; and sodium-potassium, sulfate-chloride. Although a listing of data for each stream and tributary is beyond the scope of this report, an indication of ranges in dissolved-solids concentrations, chemical type, and sediment concentration are given in table IV–19 (*136*).

Customarily, each irrigation project diverts water at one point in the river and the "return flow" comes back into the mainstream somewhere below the system. This return flow consists in the main of: (1) regulatory water, the unused part of the diverted water required so that each farmer irrigating can have the exact flow he has ordered; (2) tail water, that portion of the water which runs off the ends of the fields; and (3) underground drainage, required to provide adequate application

TABLE IV–19. Variations in Dissolved Solids, Chemical Type, and Sediment (136). Rivers in Arid and Semiarid United States

Region	Dissolved solids concentrations, mg/l		Prevalent chemical type [1]	Sediment concentrations, mg/l [2]	
	From	To		From	To
Columbia River Basin	<100	300	Ca-Mg, C-b	<200	300
Northern California	<100	700	Ca-Mg, C-b	<200	+500
Southern California	<100	+2,000	Ca-Mg, C-b; Ca-Mg, S-C	<200	+15,000
Colorado River Basin	<100	+2,500	Ca-Mg, S-C; Ca-Mg, C-b	<200	+15,000
Rio Grande Basin	<100	+2,000	Ca-Mg, C-b; Ca-Mg, S-C	+300	+50,000
Pecos River Basin	100	+3,000	Ca-Mg, S-C	+300	+7,000
Western Gulf of Mexico Basins	100	+3,000	Ca-Mg, C-b; Ca-Mg, S-C; Na-P, S-C.	<200	+30,000
Red River Basin	<100	+2,500	Ca-Mg, S-C; Na-P, S-C	+300	+25,000
Arkansas River Basin	100	+2,000	Ca-Mg, S-C; Ca-Mg, C-b; Na-P, S-C.	+300	+30,000
Platte River	100	+1,500	Ca-Mg, C-b; Ca-Mg, S-C	+300	+7,000
Upper Missouri River Basin	100	+2,000	Ca-Mg, S-C; Na-P, C-b; Na-P, C-b.	<200	+15,000

[1] Ca-Mg, C-b = Calcium-magnesium, carbonate-bicarbonate.
Ca-Mg, S-C = Calcium-magnesium, sulfate-chloride.
Na-P, C-b = Sodium-potassium, carbonate-bicarbonate.
Na-P, S-C = Sodium-potassium, sulfate-chloride.

[2] Sediment concentration $= \frac{\text{Annual Load}}{\text{Annual Streamflow}}$

and salt balance in all parts of the fields. The initial flush of tail water may be somewhat more saline than later, but rapidly approaches the same quality as the applied water (*141*).

In many projects, however, a large part of the unused water supply does get into the soil, through seepage from ditches and from amounts entering the irrigated soil in excess of that utilized in evapotranspiration. Such waters that have entered the soil are more saline and do return to the downstream supply by one means or another. It is axiomatic that water is actually used and reused numerous times in a river system and there will be progressive concentration of salts except as the mainstream is diluted by tributaries.

Drainage and leaching requirement

Addition of irrigation water in excess of that required for plant use is necessary to prevent salt accumulation in the soil. This is referred to as the leaching requirement. It is possible to predict the approximate salt concentration that would occur in the soil after a number of irrigations by estimating the proportion of applied water that will percolate below the root zone. In any steady state leaching formula, the following assumptions are made:

(1) No precipitation of salts occurs in the soil;
(2) Ion uptake by plants is negligible;
(3) Uniform distribution of soil moisture through the profile and uniform concentration of salts in the soil moisture;
(4) Complete and uniform mixing of irrigation water with soil moisture before any of the moisture percolates below the root zone; and
(5) Residual soil moisture is negligible.

A steady state leaching requirement formula has been developed by the U.S. Salinity Laboratory (*181*) designed to estimate that fraction of the irrigation water that must be leached through the root zone to control soil salinity at any specified level. This is given as:

$$LR = \frac{D_{dw}}{D_{iw}} = \frac{EC_{iw}}{EC_{dw}}$$

where LR = leaching requirement;
D_{dw} = depth of drainage water;
D_{iw} = depth of irrigation water;
EC_{iw} = salinity of irrigation water;
EC_{dw} = salinity of water percolating past root zone.

Hence, if EC_{dw} is determined by the salt tolerance of the crop to be grown, and the salt content of the irrigation water EC_{iw} is known, the fraction can be calculated. This will then determine the relationship between the depths of irrigation and drainage water which must be applied. Since EC_e (electrical conductivity of the soil solution extract) is a diluted index value relative to the actual EC of the soil water, and since EC_{dw} is the permissible salt concentration at the bottom of the root zone with the mean level of soil salinity being considerably less, the EC_e value for 50-percent yield reduction for a particular crop has been recommended as a guide for EC_{dw}. The actual yield reduction probably would be less than 50 percent (*15*).

Bernstein (*16*) has developed a leaching fraction formula which takes into consideration factors that control leaching rates such as infiltration rate, climate (evapotranspiration), frequency and duration of irrigation, and, of course, the salt tolerance of the crops. He defines the leaching fraction as $LF = 1 - ET_c/IT_i$ where LF = the leaching fraction or proportion of applied water percolating below the root zone; E = the average rate of evapotranspiration during the irrigation cycle, T_c; and I = the average infiltration rate during the period of infiltration, T_i. By utilizing both the required leaching derived from the steady-state formula

$$LR = \frac{EC_{iw}}{EC_{dw}}$$

and the leaching fraction based upon infiltration rates and evapotranspiration during the irrigation cycle, it is possible to estimate whether adequate leaching can be attained or whether adjustments must be made in the crops to be grown to permit higher salinity concentrations.

In addition to determination of crops that should be grown, leaching requirements may be used to indicate the total quantities of water that will be required. For example, irrigation water with a conductivity of 2 millimhos requires one-sixth more water to maintain root zone salt concentrations within 8 millimhos than would water with a salt concentration of 1 millimho under the same conditions of use. In other words, where 600 acre-feet of less saline water would suffice, 700 acre-feet of the more saline water would be required to accomplish the same result.

There are problems with applying the leaching requirement concept in actual practice. In the first place, it is not practical to apply water with complete uniformity. In surface irrigation, the objective is to apply the same amounts of water to all parts of the field; but particularly in view of the ever-increasing cost of skilled labor, some parts of a field may receive more water than others. Generally, land is not sufficiently leveled to achieve an even depth of water application. With sprinkler irrigation, there is a common need, particularly in the arid and semiarid regions, of keeping application rates low. This need is in conflict with attempts to approach complete uniformity of coverage. Optimum sprinkler uniformity of coverage is about 85 percent under still conditions and less with wind.

Secondly, soils are far from uniform, particularly with respect to vertical hydraulic conductivity. Considerable nonuniformity must be expected, far more in areas of discontinuous stratification than elsewhere.

Thirdly, the effluent from tile or ditch drains may not be representative of the salinity of water at the bottom of the root zones. The streamlines of flow from the water table to the tile go to considerable depths; and in a newly reclaimed area particularly, the ground water below the tile system may be undergoing considerable freshening. Recent studies in the San Joaquin Valley of California indicate that this freshening will go on for 50 years (*134*).

Fourthly, there is a considerable variation in drainage outflow which has no relation to leaching requirement when different crops are irrigated (*131*). This results from variations in irrigation practices for the different crops.

The leaching requirement concept while very useful should not be used as a sole guide in the field. The leaching requirement is a long-period average value which can be departed from for short periods with adequately drained soils to make temporary use of water poorer in quality than customarily applied.

The exact manner in which leaching occurs and the appropriate values to be used in leaching requirement formulae require further study. The many variables and assumptions involved preclude a precise determination under field conditions.

Specific problem areas

Salinity Hazard

Waters with TDS less than about 500 mg/l are used by farmers without awareness of any salinity problem, unless, of course, there is a high water table (*97*). Also, without dilution from precipitation or an alternative supply, waters with TDS of about 5,000 mg/l usually have little value for irrigation (*130*). Within these limits, the *value* of the water appears to decrease as the salinity increases. Where water is to be used regularly for the irrigation of relatively impervious soil, its value is limited if the TDS is in the range of 2,000 mg/l.

The following classification as to salinity hazard is suggested:

	TDS mg/l	*EC mmhos/cm*
Water for which no detrimental effects will usually be noticed	<500	<0.75
Water which can have detrimental effects on sensitive crops	500–1,000	0.75–1.50
Water that may have adverse effects on many crops and requiring careful management practices	1,000–2,000	1.50–3.00
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000–5,000	3.00–7.50

Permeability Hazard

There are two criteria that are used to evaluate the effect of certain salts in the irrigation water on soil permeability. One of these is the sodium adsorption ratio (SAR) and its relation to the exchangeable sodium percentage. The other of these is the bicarbonate hazard which is particularly applicable to arid region irrigation agriculture. Eaton (*47*) developed the concept of "residual sodium carbonate" (RSC) for characterizing water quality. More recently, Bower, et al. (*23, 24*) found that the hazard is related to the tendency of calcium carbonate to be precipitated from the soil solution, as indicated by the Langelier index (*83*) and to the fraction of inflow water evapotranspired. In other words, the greater the tendency of the soil water to precipitate $CaCO_3$ during the evapotranspiration concentration process between irrigations, the more rapidly SAR of that soil water increases. Thus, there is a relationship between SAR and bicarbonate hazard, as suggested by Doneen (*41, 42*), but any specific relationship is affected by irrigation management practices. In general, the bicarbonate hazard presents the greatest problem at low salt concentrations.

Another problem with a permeability hazard is that permeability tends to increase and the stability of a soil to any ESP level increases as the salinity of the soil water increases (*135*). The work of Rollings gives the most recent information on the interrelationships of EC, SAR, and soil structure stability (*144*).

Doneen (*41*) has long suggested that precipitable calcium carbonate and the precipitable calcium sulfate be deducted from total salinity to get what he calls "effective salinity." Christiansen and

Thorne (*37*) raise a similar question regarding the bicarbonates. Waters high in bicarbonate relative to other anions can affect permeability more than their SAR would indicate. Coachella Valley of California was formerly irrigated with well water. Some well waters low in salt and low in SAR but relatively high in bicarbonate created highly impervious soils. The problem disappeared upon introduction of Colorado River water, higher in salts than the well water used, but having a positive Langelier index—a strong tendency to deposit calcium carbonate.

In summary, water with SAR values between eight and 18 may have an adverse effect on permeability of soils containing an appreciable amount of clay. The specific SAR value that has this effect increases as the salinity increases. Low salt water high in bicarbonates may present a permeability hazard even at low SAR values.

Suspended Solids

Suspended organic solids in surface water supplies seldom give trouble in ditch distribution systems except for occasional clogging of gates and for carrying weed seeds onto fields where subsequent growth of weeds can have a severely adverse effect on the crop, but also may have a beneficial effect by reducing seepage losses. Where surface water supplies are distributed through pipelines, it is often necessary to have self-cleaning screens to prevent clogging of the pipe system appliances. Finer screening is usually required where water enters pressure-pipe systems for sprinkler irrigation.

There are waters diverted for irrigation that carry heavy inorganic sediment loads. The effects that these loads might have depends in part on the particle-size distribution of the suspended material. The ability of sandy soils to store available moisture has been greatly improved after being irrigated with muddy water for a period of years. More commonly, sediment tends to fill canals and ditches, causing serious cleaning and dredging problems. It also tends to further reduce the already low infiltration characteristics of slowly permeable soils. Kennedy (*76*) developed criteria to keep sediments moving in irrigation canals to prevent deposition. These criteria worked very well with the somewhat coarser sediments of the Indus River system where they were developed, but are not universally adaptable. In most waters carrying appreciable amounts of sediments, provision is usually made now for most to be settled out and be bypassed back to the mainstream near the point of diversion.

specific irrigation water quality considerations for humid regions

Environmental factors

Climate

The most striking feature of the climate of the humid region that contrasts with that of the far West and intermountain areas is the larger amount of, and less seasonable distribution of, the precipitation. Rainfall, rather than lack of it, is the normal expectation. There are perhaps more cases in which crops are damaged because of too much water than because of too little. Yet, droughts are common enough to require that attention be given to supplemental irrigation. These times of shortage of water for optimum plant growth can occur at irregular intervals and at almost any stage of plant growth.

Water demands per week or day are not as high in humid as in arid lands. But rainfall isn't easily predicted. Thus a crop may be irrigated and immediately thereafter receive a rain of one or two inches. Supplying the proper amount of supplemental irrigation water at the right time is not easy even with adequate equipment and a good water supply. There can be periods of several successive years when supplemental irrigation is not required for most crops in the humid area. There are times, however, when supplemental water can increase yield or avert a crop failure. Supplemental irrigation for high-value crops will undoubtedly increase in humid areas in spite of the fact that much capital is tied up in irrigation equipment during years in which little or no use is made of it.

The range of temperatures in the humid region in which supplemental irrigation is an appreciable factor is almost as great as that mentioned for the arid and semiarid areas. It ranges from the specialty crop production in the short growing season of upstate New York and Michigan to the continuous growing season of southern Florida. But in the whole of this area, the most unpredictable factor in crop production is the need for additional water for optimum crop production.

Soils

The soils of the humid region contrast with those of the West primarily in being lower in available nutrients. They are also generally more acid and may have problems with exchangeable aluminum. The texture of soils is similar to that found in the West and ranges from sands to clays. Also, some are too permeable while others take water very slowly.

Soils of the humid region generally have clay minerals of lower exchange capacity than soils of the arid and semiarid regions and hence lower buffer capacity. They are more easily saturated with anions and cations. This is an important consideration if irrigation with brackish water is necessary to supplement natural rainfall. Organic matter content ranges from practically none on some of the Florida sands to the high amounts found in some irrigated mucks and peats.

One of the most important characteristics of many of the soils of the humid Southeast is the unfavorable root environment of the deeper horizons containing exchangeable aluminum and having a strong acid reaction. In fact, the lack of root penetration of these horizons by most farm crops is the primary reason for the need for supplemental irrigation during short droughts. If soil and water management practices would permit roots to penetrate another foot or two, many irrigations would not be needed. Sometimes normally deep-rooted crops such as alfalfa will wilt or stop growing when there is plenty of available water at a depth as shallow as 2 feet.

Though there are some relatively level irrigated areas in the humid region, as a whole the landscape is more uneven than the irrigated areas of the arid and semiarid regions. Because of this, and because of the occasional nature of supplemental irrigation in the humid area, sprinkler systems are used almost exclusively. The nature of the landscape limits the naturally available supplies of water that can be used for supplemental irrigation.

Specific Difference Between Humid and Arid Regions

The effect of a specific water quality deterrent on plant growth is governed by related factors. Basic principles involved are almost universally applicable, but the ultimate effect must take into consideration these associated variables. It has been previously stated that the effect of any given water quality deterrent on plant growth is greatly affected by the sensitivity of that plant to the deterrent, soil characteristics, and the climatic environment. The amount of irrigation water used and soil drainability are also contributing factors. For this reason, water quality criteria for supplemental irrigation in humid areas may differ from those indicated for arid and semiarid areas where the water requirements of the growing plant are met almost entirely by irrigation.

Plant sensitivity to a given deterrent is a fixed characteristic of a given species. When irrigation water containing a deterrent is used, its effect on plant growth may vary, however, with the stage of growth at which the water is applied. In arid areas, plants may be subjected to the influence of irrigation water quality continuously from germination to harvest. Where water is used for supplemental irrigation only, the effect on plants will depend not only upon the growth stage at which applied, but to the length of time that the deterrent remains in the root zone (*95*). Leaching effects of intervening rainfall must be taken into consideration.

Quality of water applied by sprinkler irrigation will affect both foliar absorption and absorption of the constituents found in that water. Although some sprinkler irrigation is found in arid and semiarid regions, it is the dominant type used for supplemental irrigation in humid regions. It is, therefore, of primary concern in the latter.

Climatic differences between humid and arid regions also influence criteria for use of irrigation water. The amount of rainfall determines in part the degree to which a given constituent will accumulate in the soil. Other factors associated with salt accumulation in the soil are those climatic conditions relating to evapotranspiration. In humid areas, evapotranspiration is generally less than in arid regions and plants are not as readily subjected to water stress. The importance of climatic conditions in relation to salinity was demonstrated by Magistad, et al. (*99*). In general, criteria regarding salinity for supplemental irrigation in humid areas can be more flexible than for arid areas.

Soil characteristics represent another significant difference between arid and humid regions. Soils in arid regions generally tend to be neutral or alkaline, whereas those in humid regions tend to be acidic. Mineralogical composition will also vary. The composition of soil water available for absorption by plant roots represents the results of an interaction between the constituents of the irrigation water and the soil complex. The final result may be that a given quality deterrent present in the water could be rendered harmless by the soil, remain readily available, or that the dissolved constituents of a water may render soluble toxic concentrations of an element which was not present in the irrigation water. An example of this would be the addition of a saline water to an acid soil resulting in a decrease in pH and a possible increase in solubility of elements such as iron, aluminum, and manganese (*51*).

Another significant characteristic of soils is their adsorption, or ion exchange, properties. Not only is the composition of the soil solution altered by dissolved constituents in irrigation water, but the physical properties of the soil may also be altered by changes in ions adsorbed by the soil.

General relationships previously derived for SAR and adsorbed sodium in neutral or alkaline soils of arid areas do not apply equally as well to acid soils found in humid regions (*92*). Furthermore, the effect of a given level of adsorbed sodium (exchangeable sodium percentage) on plant growth will be determined to some degree by the associated adsorbed cations. The amount of adsorbed calcium and magnesium relative to adsorbed sodium is of considerable consequence, especially when comparing acidic soils to ones which are neutral or alkaline. Another example would be the presence of a trace element in the irrigation water which might be rendered insoluble when applied to a neutral or alkaline soil, but retained in a soluble, available form in acid soils. For these reasons, soil characteristics, which differ greatly between arid and humid areas, must be taken into consideration.

Certain economic factors also influence water quality criteria for supplemental irrigation. Although the ultimate objective of irrigation is to insure efficient and economic crop production, there may be instances where an adequate supply of good quality water is unavailable to achieve this. A farmer may be faced with the need to use irrigation water of inferior quality to get some economic return and prevent a complete crop failure. This can occur in humid areas during periods of prolonged drought. Water quality criteria are generally designed for optimum production, but consideration must be given also to supplying guidelines for use of water of inferior quality to avert a crop failure.

Specific quality criteria for supplemental irrigation

A previous discussion of potential quality deterrents contained a long list of factors indicating the current state of our knowledge as to how they might relate to plant growth. Criteria can be established in two ways: (a) by determining a concentration of a given deterrent which when adsorbed on, or absorbed by, a leaf during sprinkler irrigation results in adverse plant growth, and (b) by evaluating the direct and/or indirect effects that a given concentration of a quality deterrent will have on the plant root environment as irrigation water enters the soil. Neither evaluation is simple, but the latter is most complex since so many variables are involved. Since sprinkler application is most common in humid areas for supplemental irrigation, both types of evaluation have considerable significance. The following discussion relates only to those quality criteria that are specifically applicable to supplemental irrigation.

Salinity

General concepts regarding soil salinity as previously discussed are applicable. Actual levels of salinity which can be tolerated for supplemental irrigation must take into consideration the leaching effect of rainfall and the fact that soils are usually nonsaline at spring planting. The amount of irrigation water having a given level of salinity that can be applied to the crop will depend upon the number of irrigations between leaching rains, the salt tolerance of the crop, and the salt content of the soil prior to irrigation. Since it is not realistic to set a single salinity value, or even a range, that would take these variables into consideration, a guide was developed to aid farmers in safely using saline, or brackish, waters (*93*). The following equation was used as a basis for this guide:

$$EC_{e(f)} = EC_{e(i)} + \frac{n(EC_{iw})}{2}$$

where $EC_{e(f)}$ = electrical conductivity of the saturation extract after irrigation is completed;

$EC_{e(i)}$ = electrical conductivity of the soil saturation extract before irrigation;

EC_{iw} = electrical conductivity of the irrigation water; and

n = number of irrigations.

To utilize this guide, one must first consider the salt tolerance of the crop to be grown and the soil salinity level [$EC_{e(f)}$] which will result in a 15 or 50-percent yield decrement for that crop. Then, after evaluating the level of soil salinity prior to irrigation [$EC_{e(i)}$] and the salinity of the irrigation water, the maximum number of permissible irrigations can be calculated. These numbers are based on the assumption that no intervening rainfall occurs in quantities large enough to leach salts from the root zone. Should leaching rainfall occur, the situation could be reevaluated using a new value for $EC_{e(i)}$.

Using values based on a 50-percent yield decrement (table IV–14, p. 150), and categorizing the salt tolerance of crops as highly salt tolerant, moderately salt tolerant and slightly salt tolerant, the guide shown in table IV–20 was prepared to indicate the number of permissible irrigations using water of varying salt concentrations. This guide is based on two assumptions:

(1) That no leaching rainfall occurs between irrigations, and

(2) That there is no salt accumulation in the soil at the start of the irrigation period. If leaching rains occur between irrigations, the effect of the added salt will be minimized. If there is an accumulation of salt in the soil initially, such as might occur when irrigating a fall crop on land to which saline water had been applied during a spring crop, the soil should be tested for salt content and the irrigation recommendations modified accordingly.

TABLE IV–20. Permissible Number of Irrigations in Humid Areas With Saline Water Between Leaching Rains for Crops of Different Salt Tolerance [1] (97)

Irrigation water		Number of irrigations for crops having		
Total salts mg/l	Electrical conductivity mmhos/cm. at 25 C	Low salt tolerance	Moderate salt tolerance	High salt tolerance
640	1	7	15	--
1,280	2	4	7	11
1,920	3	2	4–5	7
2,560	4	2	3	5
3,200	5	1	2–3	4
3,840	6	1	2	3
4,480	7	--	1–2	2–3
5,120	8	--	1	2

[1] Based on a 50-percent yield decrement.

SAR Values and Exchangeable Sodium

The principles relating to this parameter and the degree to which sodium is adsorbed from water by soils are generally applicable in both arid and humid regions. Some evidence is available (*92*), however, to indicate that, for a given water quality, less sodium is adsorbed by an acid soil than by a base-saturated soil. For a given level of exchangeable sodium, preliminary evidence indicates more detrimental effects on acid soils than on base-saturated soils (*94*). Since experimental evidence is not conclusive at this point, detrimental limits for SAR values previously listed will also apply to supplemental irrigation.

Acidity and Alkalinity

The effect of the pH of irrigation water on crops results primarily from the resultant effect on the soil to which it is applied. The only consideration not previously discussed relates to soil acidity which is more prevalent in humid regions where supplemental irrigation is practiced. Any factor which will drop the pH below 4.8 may render soluble toxic concentrations of iron, aluminum, and manganese. This might result from application of a highly acidic water, or from a saline solution applied to an acidic soil. Since the nature of the soil is the major determining factor, it is not feasible to set limits on the pH of the water. Specific consideration must be given to each individual set of conditions.

Trace Elements

Criteria and related factors previously listed are equally applicable to supplemental irrigation. Certain related qualifications must be kept in mind, however. First, foliar absorption of trace elements in toxic amounts is directly related to sprinkler irrigation. Critical levels established for soil or culture solutions would not apply to direct foliar injury. Regarding trace element concentrations in the soil resulting from irrigation water application, the volume of the water applied by sprinkler as supplemental irrigation is much less than that applied by furrow or flood irrigation in arid regions. In assessing trace element concentrations in irrigation water, therefore, total volume of water applied and the physicochemical characteristics of the soil must be taken into consideration. Both of these factors could result in different standards or criteria for supplemental irrigation as compared with surface irrigation in arid regions.

Organic Compounds

These are primarily pesticides, but may also contain other types of organic quality deterrents originating from domestic and industrial sources. Here again, quantity applied, soil characteristics, and plant sensitivity must be taken into consideration.

BOD and Aeration

Although not a problem in normal irrigation waters, it could be a problem where certain processing plant effluents are involved. Using sprinkler application for supplemental irrigation, the combined effects of the sprinkling and infiltration into the soil provide considerable aeration which would minimize this hazard. Where sprinkler irrigation is used for effluent disposal and where the soil remains excessively wet for long periods of time, BOD may become a deterring factor, but no specific information is available to enable quantification.

Suspended Solids

Two factors regarding suspended solids must be taken into consideration for sprinkler irrigation, which are not significant for surface irrigation. The first deals with the plugging up of sprinkler nozzles by these sediments. Size of sediment is a definite factor, but no specific particle size limit can be established. Of the larger sediment particles that do pass through the sprinkler, much of these can be washed off certain leafy vegetable crops. Some of the finer fractions, suspended colloidal material, could accumulate on the leaves and, once dry, are extremely difficult to wash off, thereby impairing the quality of the product. These hazards increase with frequency of irrigation and volume of water applied.

other considerations

Adequacy and achievability of criteria

Of all the criteria discussed, most information is available regarding salinity. Yet a careful review of this material indicates that it is most difficult to assign tolerance limits, or even ranges of values, for irrigation water. All research points to the interactive effects of water table depth, soil type, plant tolerances, and climatic conditions. Soil salinity itself is not only a function of salinity level of the irrigation water, but also the volume and rate of application and leaching effects of intervening rainfall. The same is true for the sodium hazard involved in certain saline waters. Adequate guidelines do exist regarding salinity; and, although a specific limit cannot be set, these guidelines can be used to judge the suitability of a given water for irrigation.

Our knowledge of the effect of trace elements in irrigation water on plant growth is extremely limited. Work cited as being done in nutrient solutions seldom provides sufficient information on toxic limits for a variety of crops. Even if this were available, the gap must be bridged between the content of that element in a given irrigation and the resultant content in the soil solution following irrigation. Here, again, availability of a given element to plants will vary with soil characteristics. In general, criteria for trace elements are inadequate and guidelines previously described are the best generalizations that can be made with existing information.

The BOD or COD value of water is important for many uses, but its significance in irrigation water has not been fully assessed. As previously mentioned, it is not likely to be a problem where sprinkler irrigation is used predominantly and adequate soil drainability is maintained. For these reasons, no specific criteria are prescribed.

It is evident that there is a great lack of information regarding quality deterrents in water for irrigation in general. Guidelines are available for some naturally occurring deterrents; but as the pollution pattern of our water sources changes, additional research will be necessary to evaluate effects of these wastes on various crops and for a range of soil conditions. This information is necessary before adequate and achievable criteria can be developed.

In view of the above discussion, it is apparent that judicious use of water of impaired quality may be more practical than water treatment. Adequate guidelines are available for salinity, but additional research is needed to develop comparable guidelines for other mineral and organic contaminants.

Steps to improve water quality

It is outside the scope of this report to discuss water treatment in detail. Limited water treatment possibilities must be reconciled with the economic value of the crop being produced. For field irrigation in general, treatment is not usually practical. Where good quality water is necessary for high value crop production in greenhouses, water treatment may be feasible. Each case must be considered on its own merits.

Nevertheless, since good water management is so germane to quality characteristics of irrigation water, brief mention will be made of several methods whereby the quality of irrigation water can be maintained or improved.

Total Dissolved Solids

Uniformity of irrigation water quality can be achieved through stream regulation by controlling release of water from storage reservoirs. Since salt contents in streams are frequently high during low flows and low during periods of high flow, intermixing in the reservoir and strategic releases of water can provide more uniform salinity levels in the irrigation water.

Evaporation of water from reservoirs tends to increase the salt content. Continuing studies are being conducted on new materials and application techniques to minimize this effect.

Elimination of nonbeneficial uses of water by phreatophytes not only lessens the concentration of salts through transpiration, but conserves water as well. Lowering the water table and developing mechanical and chemical techniques for elimination of phreatophytes will insure more efficient water use and minimize salt hazards.

Salts are frequently added to irrigation water from mineral springs, oil wells, industrial enterprises, mine waters, and urban areas. Each of these sources must be considered individually to determine effective control measures.

Regulation of return flows according to quantity and quality is another means of maintaining and improving irrigation water quality. Utilization of ponds and reservoirs to control streamflow can be helpful in this respect.

Drainage water from irrigated lands in arid regions is commonly more saline than the applied water. This is especially true where reclamation of saline soils is in progress. In coastal areas, irrigation water quality can be maintained by bypassing saline return flows directly to the ocean.

Desalting water may be a potential in the future when technology permits production at a relatively low cost. Desalted water can be used directly for irrigation, for augmenting low flows, or for mixing with poor quality water. For the use of desalted water to be feasible, adequate opportunities for disposal of the resulting brine must be available.

Water shortages in some areas emphasize the need for conjunctive use of ground and surface waters. One aspect of this involves more effective use of ground water storage potential. Increasing ground water recharge to make use of this potential would be most beneficial. The threat of gradual deterioration in ground water quality through difficulties in achieving basin salt balance could be mitigated by greatly expanded utilization of ground water storage resources.

Sediment

One of the major ways of minimizing the sediment burden of streams is through proper watershed management. Practices designed to provide effective ground cover, improve soil infiltration characteristics, and stabilize waterways will insure both efficient water conservation and help avoid excessive soil loss. Sediment control is best effected at its source: the watershed.

Unstable stream channels are another important source of sediment. Rectification of stream channels and stabilization of streambanks will minimize sediment production from this source.

Once sediment occurs in streams, it can be removed where impoundments are used. The construction of sediment traps has proved to be very effective for this purpose, if properly designed. Another possibility is the construction of desilting works at diversion points. Chemicals have also been used for flocculating colloidal sediments.

Phytotoxic Substances

The control of phytotoxic substances in irrigation water is difficult. Where these materials originate from industrial or municipal sources, control should be focused at the point of origin. Once they are present in irrigation water, removal is not economically feasible. Substances such as insecticides and herbicides can be hazardous if misused. Control of the use of these materials can prevent their becoming a problem in irrigation agriculture. There are good indications that eliminating tail water and other surface returns from irrigation provides an excellent means for reducing and controlling pesticide residues in return flows (*73*).

Monitoring and measuring

Certain principles relating to monitoring and measuring water quality are common to all agricultural uses. These will be discussed later. There are, however, certain factors peculiar to irrigation water sources which should be pointed out.

Sampling of water for analysis on a daily or periodic basis will depend upon numerous variables, including: sources and adequacy of water supply, crops grown, discharges of water quality deterrents into the stream above the points of diversion, and geographic location of irrigated areas with respect to sources of supply.

Monitoring of water supplies on a scheduled or unscheduled basis provides information for daily or weekly irrigation unit operational purposes and checks on changes in water quality resulting from upstream changes. The frequency of sampling and analysis for operational purposes will be dependent upon previously obtained and correlated data with the timing of additional samples and parameters to be evaluated, based upon conditions peculiar to each geographic area. If significant changes in concentrations or constituents are noted from water samples taken, increased frequency of sampling and additional monitoring points may be desirable. Possibility of industrial wastes upstream should be evaluated.

Historical water quality data should be reviewed when considering the type, location, and frequency of sampling. If such data are not available, a systematic water quality sampling program to provide background information is often desirable to evaluate changes in water quality which may occur with time.

Water for a given area may be obtained from one or more sources; i.e., ground water, one or more surface reservoirs, unregulated streamflows, and return flows from other uses. The ground water source may be directly used by pumping from the formation, or by ground water discharges to a river upstream of the point of irrigation diversion. As quality variations usually occur very slowly in underground supply sources, sampling of the source can be at intervals of several months and often can be safely taken on a yearly basis. In instances where ground water discharges upstream from the point of diversion form a significant portion of the total supply, depletion of the ground water discharge may affect the quality of water in the stream. Under such conditions, prudent management would provide for regular assessment of sources and the quality implications of changes in available supplies.

Unregulated streams can be expected to have the largest fluctuations in water quality throughout the year. Monitoring programs for such streams generally will require sampling at more frequent intervals. During periods of flood flows, monitoring of suspended solids is important. The frequency of sampling can be reduced as the percentage of the stream system regulated by reservoirs is increased.

Operation of reservoirs can improve the quantity and quality of water at downstream locations. At locations where water temperatures may be an important variable to monitor, vertical profiles of reservoir water temperature should be obtained before releases; and, where possible, water should be released from that segment of reservoir having the most favorable temperature. With reservoirs on two or more streams supplying water to the same lands, adequate data should be obtained to provide for either operational blending of supplies or to indicate that direct delivery will not have any adverse effects on lands or crops.

sampling and analytical procedures

MONITORING water for specific pollutants requires acceptable sampling and analytical procedures and the following references contain such guides and procedures. This doesn't preclude the use of other reliable methods (*21*, *123*, *137*, *159*, *175*, *181*).

The methodology for pesticides is currently somewhat dispersed. For purposes of clarity and as an aid to laboratories, the following recommended instructions for extraction and analysis are set forth.

Methods for Analyses of Chlorinated and Phosphate Pesticides in Water

For extraction and preparation of the samples for multiple detection (electron capture or thermionic gas-liquid chromatography and confirmation by thin-layer chromatography), follow the methods of Burchfield, et al. as outlined in Analysis of Pesticide Residues (*174*).

General Discussion of extraction of pesticides from water. Generally, in batch-method extraction, chloroform is the solvent of choice, with the following modifications. After extraction, pass the combined chloroform extracts through a column of anhydrous sodium sulfate, collecting the eluate in a 500 ml Kuderna-Danish evaporator fitted with a calibrated collection tube. When all of the extract has passed through, rinse the column with three 5 ml portions of hexane. Add a 20-mesh carborundum boiling chip and place a Snyder column on the Kuderna-Danish evaporator and concentrate to about 5 ml. Add 25 ml hexane to evaporator and concentrate to about 5 ml. Repeat addition of hexane and concentrate two more times to eliminate most of the chloroform. After last evaporation, dilute to 10 ml with hexane for determination by electron-capture gas chromatography and confirmation by thin-layer chromatography.

Continuous methods are used only when it is necessary to extract large volumes of water and are adapted more to research purposes than to routine analysis.

In determinations, no cleanup is necessary if potable water is being analyzed and the analyst can go directly to electron-capture or thermionic gas chromatography with thin-layer chromatography for confirmation if necessary. Operating parameters, retention times, and supporting data are found in the FDA pesticide analytical manual (*173*). The complete methods are given A.O.A.C. 79th annual meeting (*33*) and changes in these methods are discussed in the A.O.A.C. 80th annual meeting (*34*).

For chlorinated pesticides, use electron-capture chromatography and methods described in A.O.A.C. 79th annual meeting (*33*). Use of the thermionic gas chromatography is discussed in the 1967 changes in methods (*34*). Additional information on use of thermionic gas chromatography can be found in other references (*62, 63*).

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Section V
industry

introduction

WATER QUALITY requirements differ so widely for the hundreds of uses to which water is put industrially that no meaningful criteria for surface water supplies can encompass a majority of such uses. Furthermore, water treatment technology in its present state of development permits the utilization of surface water of literally *any* available quality to create waters of any desired quality at point of use. Such treatment may be costly, but this cost is usually a small part of the total production and marketing costs. The National Technical Advisory Subcommittee for Water Quality Requirements for Industrial Water Supplies has identified the appropriate quality characteristics of raw waters that have been used and the quality requirements of waters at the point of use for each industry.

Each value given in this report for a quality characteristic of raw water supplies for industrial purposes has occurred in water that has been used somewhere in this country. However, the characteristic values may be altered by treatment to produce the quality of water required at point of use. Hence, tables listing desired water quality criteria at the point of use prior to internal conditioning have been developed for each major industrial requirement.

summary and key criteria

TABLE V–1. Task Forces and Their Assignments

Task Force	Assignment	
I	Steam generation and cooling.	All SIC codes and electric utilities.
II	Textile, lumber, paper, and allied products.	SIC 22, 24, and 26.
III	Chemicals and allied products.	SIC 28.
IV	Petroleum and coal products.	SIC 29.
V	Primary metal industries	SIC 33.
VI	Food and kindred products, and leather tanning and finishing.	SIC 20 and 31.

Conclusions

The Subcommittee has reached the following conclusions regarding the water quality characteristics and requirements for industrial supplies.

(1) The quality characteristics of the water supply for an established industry at a given site, if allowed to deteriorate from the range usually experienced for those characteristics of significance to that industry, can cause an undesirable increase in the cost for treatment. On the other hand, an improvement in the quality of the same supply will not significantly decrease the cost of treatment at an existing installation.

(2) Marked variations in the quality of an industrial water supply can result in deterioration of product quality for some industries.

(3) The water quality requirements at the point of use in each process in each industry as distinguished from the quality characteristics at the point of supply are generally well established for each existing industrial process use. These water quality requirements, however, vary considerably even for the same process depending upon the technological age of the design and other factors.

(4) The quantity of water employed for process use by different plants in the same industry may vary considerably between plants depending on the cost of treatment, the age of the plant design, operating practices, and the quality and quantity of the available supply.

Industries considered

The Subcommittee was subdivided into six task forces. Task force I was concerned with water used for cooling and steam generation for all industries. Each of the other task forces was assigned one or more industrial groups as defined by the 2-digit Standard Industrial Classification (SIC) coding used by the Bureau of Census (*6*). Table V–1 lists the task forces and identifies the industrial group or groups of concern. Additional detail on the material considered is included in the sections prepared by the several task forces.

Although it has not been feasible to cover all industries, the major users of water, including some industries that require process waters having a wide range of quality, have been considered.

Water use

The total water intake of both industrial manufacturing plants and investor-owned thermal electric utilities was approximately 49,000 billion gallons during 1964. About 90 percent or 44,000 billion gallons per year (bgy) of all intake water was used for cooling or condensing purposes. Water used for processing, including water coming into contact with the product as steam or as coolant, amounted to nearly 8 percent (3,700 bgy) of the total water intake. The remaining 2 percent (960 bgy) was used for boiler-feed water.

Brackish water, water containing more than 1,000 mg/l dissolved solids, amounted to nearly 30 percent (15,000 bgy) of the total intake water. Most (32,000 bgy) of the fresh water intake (34,000 bgy) was surface water delivered by company-owned water systems.

The manufacturing industry used approximately 4,300 billion gallons of water that they treated or secured from a public supply in 1964. This was 30 percent of water intake for manufacturing and approximates 90 percent of all water that they used for boiler feed and processing.

Table V–2 summarizes the information on water intake, recycling, and consumption, for each industrial group considered.

Raw water quality

In general, the procedure used by the individual task forces involved first establishing the quality requirements for various waters at point of use exclusive only of the addition of internal conditioning chemicals such as biocides, or corrosion or deposit inhibitors. Second, the consideration of methods of external treatment (e.g. clarification, softening, demineralization, etc.) that have been used; and finally establishing the quality characteristics of raw surface waters that have been used by the various industries.

Minimum standards

Minimum standards that should be met by all surface waters for all uses include the following (*3*). The water should be:

(1) Free from substances attributable to mu-

TABLE V–2. Industrial and Investor-Owned Thermal Electric Plant Water Intake, Reuse, and Consumption, 1964

[Source: 1963, census of manufacturers, water use in manufacturing (*7*), and water resources activities in the United States—electric power in relation to the Nation's water resources (*8*)]

		Water intake (bgy)							
		Purpose							
SIC	Industrial group	Cooling and condensing	Boiler feed sanitary service, etc.	Process	Total	Water recycled (bgy)	Gross water use, including recycling (bgy)	Water consumed (bgy)	Water discharged (bgy)
20	Food and kindred products.	392	104	264	760	520	1,280	72	688
22	Textile mill products	24	17	106	147	163	310	13	134
24	Lumber and wood products.	71	24	56	151	66	217	28	123
26	Paper and allied products.	607	120	1,344	2,071	3,945	6,016	129	1,942
28	Chemicals and allied products.	3,120	202	564	3,886	3,688	7,574	227	3,659
29	Petroleum and coal products.	1,212	99	88	1,399	4,763	6,162	81	1,318
31	Leather and leather products.	1	1	14	16	2	18	1	15
33	Primary metal industry.	3,387	195	996	4,578	2,200	6,778	266	4,312
	Subtotal	8,814	762	3,432	13,008	15,347	28,355	817	12,191
	Other industries	571	197	271	1,039	1,207	2,246	71	968
	Total industry	9,385	959	3,703	14,047	16,554	30,601	888	13,159
	Thermal electric plants	34,849	([1])	------	34,849	5,815	40,664	68	34,781
	Total	44,234	959 [2]	3,703	48,896	22,369	71,265	956	44,940

[1] Boiler-feed water use by thermal electric plants estimated to be equivalent to industrial sanitary service, etc., water use.

[2] Total boiler-feed water.

TABLE V–3. Summary of Specific Quality Characteristics of Surface Waters That Have Been Used as Sources for Industrial Water Supplies

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristic	Boiler makeup water		Cooling water				Process water							
			Fresh		Brackish[a]									
	Industrial 0 to 1,500 psig	Utility 700 to 5,000 psig	Once through	Makeup recycle	Once through	makeup recycle	Textile industry, SIC-22	Lumber industry, SIC-24	Pulp and paper industry, SIC-26	Chemical industry, SIC-28	Petroleum industry, SIC-29	Prim. metals industry, SIC-33	Food and kindred products, SIC-20	Leather industry, SIC-31
Silica (SiO_2)	150	150	50	150	25	25	-----	-----	50	-----	50	-----	For the above 2 categories the quality of raw surface supply should be that prescribed by the NTA Subcommittee on Water Quality Requirements for Public Water Supplies.	
Aluminum (Al)	3	3	3	3	-----	-----	-----	-----	-----	-----	-----	-----		
Iron (Fe)	80	80	14	80	1.0	1.0	0.3	-----	2.6	5	15	-----		
Manganese (Mn)	10	10	2.5	10	0.02	0.02	1.0	-----	-----	2	-----	-----		
Copper (Cu)	-----	-----	-----	-----	-----	-----	0.5	-----	-----	-----	-----	-----		
Calcium (Ca)	-----	-----	500	500	1,200	1,200	-----	-----	-----	200	220	-----		
Magnesium (Mg)	-----	-----	-----	-----	-----	-----	-----	-----	-----	100	85	-----		
Sodium and potassium (Na+K)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	230	-----		
Ammonia (NH_4)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----		
Bicarbonate (HCO_3)	600	600	600	600	180	180	-----	-----	-----	600	480	-----		
Sulfate (SO_4)	1,400	1,400	680	680	2,700	2,700	-----	-----	-----	850	570	-----		
Chloride (Cl)	19,000	19,000	600	500	22,000	22,000	-----	-----	200[f]	500	1,600	500		
Fluoride (F)	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.2	-----		
Nitrate (NO_3)	-----	-----	30	30	-----	-----	-----	-----	-----	-----	8	-----		
Phosphate (PO_4)	-----	50	4	4	5	5	-----	-----	-----	-----	-----	-----		
Dissolved solids	35,000	35,000	1,000	1,000	35,000	35,000	150	-----	1,080	2,500	3,500	1,500		
Suspended solids	15,000	15,000	5,000	15,000	250	250	1,000	(c)	-----	10,000	5,000	3,000		
Hardness ($CaCO_3$)	5,000	5,000	850	850	7,000	7,000	120	-----	475	1,000	900	1,000		
Alkalinity ($CaCO_3$)	500	500	500	500	150	150	-----	-----	-----	500	-----	200		
Acidity ($CaCO_3$)	1,000	1,000	0	200	0	0	-----	-----	-----	-----	-----	75		
pH, units	-----	-----	5.0-8.9	3.5-9.1	5.0-8.4	5.0-8.4	6.0-8.0	5-9	4.6-9.4	5.5-9.0	6.0-9.0	3-9		
Color, units	1,200	1,200	-----	1,200	-----	-----	-----	-----	360	500	25	-----		
Organics:														
Methylene blue active substances.	2[d]	10	1.3	1.3	-----	1.3	-----	-----	-----	-----	-----	-----		
Carbon tetrachloride extract.	100	100	(e)	100	(e)	100	-----	-----	-----	-----	-----	30		
Chemical oxygen demand (O_2).	100	500	-----	100	-----	200	-----	-----	-----	-----	-----	-----		
Hydrogen sulfide (H_2S).	-----	-----	-----	-----	4	4	-----	-----	-----	-----	-----	-----		
Temperature, F	120	120	100	120	100	120	-----	-----	95[f]	-----	-----	100		

[a] Water containing in excess of 1,000 mg/l dissolved solids.
[b] May be ≤ 1,000 for mechanical pulping operations.
[c] No large particles ≤ 3 mm diameter.
[d] 1 mg/l for pressures up to 700 psig.
[e] No floating oil.
[f] Applies to bleached chemical pulp and paper only.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1) or APHA Standard methods for the examination of water and wastewater (5).

nicipal, industrial, or other discharges, or agricultural practices that will settle to form putrescent or otherwise objectionable sludge deposits;

(2) Free from floating debris, oil, scum, and other floating materials attributable to municipal, industrial, or other discharges, or agricultural practices in amounts sufficient to be unsightly or deleterious;

(3) Free from materials attributable to municipal, industrial, or other discharges, or agricultural practices producing color, odor or other conditions in such a degree as to cause a nuisance.

Additional quality characteristics of surface waters that have been used as sources for industrial water supplies are summarized in table V–3. The specific water characteristics are maximums and no water will have all of the maximum values shown.

Because of the very extensive use of water for cooling and boiler-feed purposes, the quality characteristics for surface waters for these purposes have been given special emphasis. In general, the surface water quality characteristics for process waters are applicable for the 2-digit SIC group of industries.

Part I.
steam generation and cooling

Description of industry

Task force I was concerned with quality criteria for water used by virtually all industries for steam generation and cooling. The task force's study included Standard Industry Classifications 20 through 39, with the exception of 23 and 27, plus the electrical utility industry. Water used for steam that comes into direct contact with a product and cooling water that comes into contact with a product were, by definition, considered to be process waters and, therefore, were not included in the report of this task force.

Steam generation and cooling are unique water uses in that they are required in almost every industry. Both uses are encountered under a very wide variety of conditions that require a correspondingly broad range of water quality criteria.

For example, steam may be generated in boilers that operate at pressures ranging from less than 10 pounds per square inch (psig) for space heating to more than 3,500 psig for electric-power generation. For any particular operating pressure, the required boiler water quality criteria depend upon many factors in addition to the water temperature in the steam generator. Thus, the amount of potentially scale-forming hardness that is present in the makeup water to a very low pressure boiler is of far less importance when the steam is used for space heating than when it is used for humidification of air. In the first case, virtually all of the steam is returned to the boiler as condensate, whereas in the second case, none of it returns to the boiler. Even when operating at the same drum pressure and makeup rate, a higher hardness is acceptable in the makeup water to boilers with low-heat transfer ratings than to those with high ratings.

From these few examples, it should be apparent that any general criteria for boiler feed water quality could not be applied directly to an individual boiler plant without further consideration of operating temperatures and pressures, boiler design, makeup rates, and steam uses. All of these affect the nature of the water-caused problems that might be anticipated in the boiler and its auxiliaries.

Cooling water uses are similarly diverse. They may be once through or recirculated. Once through cooling waters are drawn from amply large sources such as rivers, lakes, or extensions of the sea. They are returned to those sources or to other large bodies of water after having passed through heat exchange equipment just once. The quantities of water required for once through cooling are so huge that it is rarely economically feasible to alter their quality by treatment. The most common exception is chlorination for control of biological organisms that interfere with waterflow or heat transfer.

In recirculating, cooling water systems, the water withdrawn from the river or lake is small in comparison with the rate of circulation through the heat transfer equipment. Under these conditions, water treatment is economically feasible. Indeed, it becomes a necessity because of the changes in water composition produced by evaporation and other processes encountered during recirculation. As in the case of steam generation, there is such a great variety of cooling equipment used, such a wide range of chemical and physical changes that can take place in the cooling water, and such a variety of water treatment and conditioning methods available, that quality criteria for makeup water to recirculating cooling systems can have only very limited practical significance. The needs of any specific system must be established on the basis of the construction and operating characteristics of that particular system.

Processes utilizing water

Steam Generation

Intake: In 1964, manufacturing plants used about 960 billion gallons of water for boiler feed (makeup), sanitary service, and uses other than process or cooling (7). No basis is given for a breakdown of this figure into its components, but boiler feed (makeup) is the larger part.

No data are available for boiler makeup requirements of thermal electric powerplants. However, these are small compared with their cooling water requirements. It is estimated, therefore, that the boiler makeup requirements of thermal powerplants approximate the "boiler-feed, sanitary service, and other uses" (7) in the industrial requirements so that the total intake for steam generation in the year 1964 is assumed to have been approximately 960 billion gallons.

Recycle: Recycle of condensed steam back to the boiler will vary from 0-percent for some industrial uses and district steam plants to almost 100 percent for thermal power generation plants.

Consumption: Boiler makeup will vary from negligible losses and blowdown in the thermal powerplants to substantially the total water intake in district steam plants with no returned steam condensate. Even for these, the condensate usually goes to a sewer from which it ultimately returns to a surface water course and so cannot be said to have been consumed.

It is estimated that 10 percent of the intake water is either lost to the atmosphere or incorporated in products. Thus, the total water consumption for steam generation is about 96 bgy.

Discharge: Discharge is boiler blowdown and steam condensate that is lost to sewers. This corresponds to the difference between intake and consumption or 860 bgy.

Cooling Waters

Once through cooling: Once through cooling water use in industry during 1964 was at the rate of approximately 2,900 bgy for steam electric power generation and 6,500 bgy for other uses (*7*).

Total cooling water use in thermal electric power plants was 27,000 bgy in 1959 and is estimated at 57,000 bgy for 1970 (*9*). Assuming for simplicity that the rate of change will be linear, the probable use for 1964 was 41,000 bgy. It is estimated that recirculation in these plants is 5,800 bgy, so that once through cooling required 35,000 bgy. These figures do not include water used in public-owned steam generation plants for which no data were available.

The total water quantities used for once through cooling are summarized in detail on the following page.

TABLE V–4. Quality Characteristics of Surface Waters That Have Been Used for Steam Generation and Cooling in Heat Exchangers

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristic	Boiler makeup water			Cooling water			
	Industrial		Electric utilities	Once through		Makeup for recycling	
	Low and medium pressure 0 to 700 psig	High pressure 700 to 1,500 psig	High pressure > 1,500 psig	Fresh	Brackish [1]	Fresh	Brackish [1]
Silica (SiO_2)	150	150	150	50	25	150	25
Aluminum (Al)	3	3	3	3	(2)	3	(2)
Iron (Fe)	80	80	80	14	1.0	80	1.0
Manganese (Mn)	10	10	10	2.5	0.02	10	0.02
Copper (Cu)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Zinc (Zn)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Calcium (Ca)	(2)	(2)	(2)	500	1,200	500	1,200
Magnesium (Mg)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Ammonia (NH_3)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Bicarbonate (HCO_3)	600	600	600	600	180	600	180
Sulfate (SO_4)	1,400	1,400	1,400	680	2,700	680	2,700
Chloride (Cl)	19,000	19,000	19,000	600	22,000	500	22,000
Nitrate (NO_3)	(2)	(2)	(2)	30	(2)	30	(2)
Phosphate (PO_4)	(2)	(2)	50	4	5	4	5
Dissolved solids	35,000	35,000	35,000	1,000	35,000	1,000	35,000
Hardness ($CaCO_3$)	5,000	5,000	5,000	850	7,000	850	7,000
Acidity ($CaCO_3$)	1,000	1,000	1,000	(2)	(2)	200	(2)
Alkalinity ($CaCO_3$)	500	500	500	500	150	500	150
pH, units	(2)	(2)	(2)	5.0–8.9	5.0–8.4	3.5–9.1	5.0–8.4
Color, units	1,200	1,200	1,200	(2)	(2)	1,200	(2)
Organics:							
Methylene blue active substances.	1	2	10	1.3	(2)	1.3	1.3
Carbon tetrachloride extract.	100	100	100	(4)	(4)	100	100
Chemical oxygen demand (O_2)	100	100	500	(2)	(2)	100	200
Odor	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Hydrogen sulfide (H_2S)	(2)	(2)	(2)	(2)	4	(2)	4
Dissolved oxygen (O_2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Temperature, F	120	120	120	100	100	120	120
Suspended solids	15,000	15,000	15,000	5,000	250	15,000	250

[1] Brackish water—dissolved solids more than 1,000 mg/l by definition 1963 census of manufacturers.

[2] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

[3] Zero, not detectable by test.

[4] No floating oil.

NOTE.—Application of the above values should be based upon analytical methods in Part 23, ASTM book of standards (1) or APHA Standard methods for the examination of water and wastewater (5).

Use:	*Water quantities, bgy*
Industrial-steam electric generation	2,856
Other	6,529
Commercial power	34,849
Total	44,234

A further detailed breakdown of these water quantities can be made by identifying the water as fresh or brackfish.

	Water quantities, bgy		
	Industrial	*Commercial power*	*Total*
Fresh	6,549	23,104	29,653
Brackish	2,836	11,745	14,581
Total	9,385	34,849	44,234

Recirculation: The quantities of water used for fresh water recirculation are shown in the tabulation and are based on the following assumptions:

	Fresh water recirculation, bgy		
	Industrial	*Commercial power*	*Total*
Intake	374	102	476
Recirculation	16,533	5,815	22,348
Consumption	249	68	317
Discharge	125	34	159

Some plants recirculate brackish water, but because of the limited number of such operations, water quantities have not been established for this type of cooling.

Significant Indicators of Water Quality

Table V–4 shows the quality characteristics of surface waters that have been treated by existing processes to produce waters acceptable for boiler makeup and cooling.

Table V–5 shows quality requirements for both boiler-feed water and cooling water at point of use. These values are for waters that have already been processed through any required "external" water treatment equipment, such as filters or ion exchangers, but have not yet received any required application of "internal" conditioning chemicals. This information is included to allow estimation of costs of treating raw waters. It does *not* imply that waters of poorer quality *cannot* be utilized for boiler-feed water or cooling in specific cases.

The values for water quality requirements at point of use must be considered only as rough guides. Thus, in the case of boiler-feed water makeup, the maximum concentrations refer to the upper end of the steam pressure range shown. Usually, more liberal concentrations are acceptable in feed water for boilers operating at lower pressures within each range. However, even here there are many deviations in practice because of differences in the construction and operation of different boilers. For example, all other things being equal, the higher the makeup rate, the higher the quality of the makeup water should be.

Water treatment processes

The water treatment processes marked by an "X" in the following table are used in producing water of the appropriate quality for either cooling or boiler makeup. Commonly used internal conditioning processes are also included. Not all of these processes are used, however, if the raw water quality is such that the treatment is unnecessary.

	Cooling		
	Once through	Recirculated	Boiler makeup
Suspended solids and colloids removal:			
Straining	X	X	X
Sedimentation	X	X	X
Coagulation	—	X	X
Filtration	—	X	X
Aeration	—	X	X
Dissolved solids modification softening:			
Cold lime	—	X	X
Hot lime soda	—	—	X
Hot lime zeolite	—	—	X
Cation exchange sodium	—	X	X
Alkalinity reduction:			
Cation exchange hydrogen	—	X	X
Cation exchange hydrogen and sodium	—	X	X
Anion exchange	—	—	X
Dissolved solids removal:			
Evaporation	—	—	X
Demineralization	—	X	X
Dissolved gases removal:			
Degasification mechanical	—	X	X
Degasification-vacuum	X	—	X
Degasification-heat	—	—	X
Internal conditioning:			
pH adjustment	X	X	X
Hardness sequestering	X	X	X
Hardness precipitation	—	—	X
Corrosion inhibition general	—	X	X
Corrosion embrittlement	—	—	X
Corrosion oxygen reduction	—	—	X
Sludge dispersal	X	X	X
Biological control	X	X	—

NOTES.— "—" Not used. "X"—May be used.

TABLE V–5. Quality Requirements of Water at Point of Use for Steam Generation and Cooling in Heat Exchangers

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. No one water will have all the maximum values shown.]

Characteristic	Boiler feed water				Cooling water			
	Quality of water prior to the addition of substances used for internal conditioning							
	Industrial			Electric utilities	Once through		Makeup for recirculation	
	Low pressure 0 to 150 psig	Intermediate pressure 150 to 700 psig	High pressure 700 to 1,500 psig	1,500 to 5,000 psig	Fresh	Brackish [1]	Fresh	Brackish [1]
Silica (SiO_2)	30	10	0.7	0.01	50	25	50	25
Aluminum (Al)	5	0.1	0.01	0.01	(2)	(2)	0.1	0.1
Iron (Fe)	1	0.3	0.05	0.01	(2)	(2)	0.5	0.5
Manganese (Mn)	0.3	0.1	0.01	(4)	(2)	(2)	0.5	0.02
Calcium (Ca)	(2)	(2)	(2)	(4)	200	420	50	420
Magnesium (Mg)	(2)	(2)	(2)	(4)	(2)	(2)	(2)	(2)
Ammonia (NH_4)	0.1	0.1	0.1	0.7	(2)	(2)	(2)	(2)
Bicarbonate (HCO_3)	170	120	48	(4)	600	140	24	140
Sulfate (SO_4)	(2)	(2)	(2)	(4)	680	2,700	200	2,700
Chloride (Cl)	(2)	(2)	(2)	(4)	600	19,000	500	19,000
Dissolved solids	700	500	200	0.5	1,000	35,000	500	35,000
Copper (Cu)	0.5	0.05	0.05	0.01	(2)	(2)	(2)	(2)
Zinc (Zn)	(2)	(2)	(2)	(4)	(2)	(2)	(2)	(2)
Hardness ($CaCO_3$)	20	(3)	(3)	(3)	850	6,250	130	6,250
Free mineral acidity ($CaCO_3$).	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
Alkalinity ($CaCO_3$)	140	100	40	(3)	500	115	20	115
pH, units	8.0–10.0	8.2–10.0	8.2–9.0	8.8–9.2	5.0–8.3	6.0–8.3	(2)	(2)
Color, units	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Organics:								
Methylene blue active substances.	1	1	0.5	(3)	(3)	(3)	1	1
Carbon tetrachloride extract.	1	1	0.5	(3)	(5)	(5)	1	2
Chemical oxygen demand (O_2).	5	5	0.5	(3)	75	75	75	75
Dissolved oxygen (O_2)	2.5	0.007	0.007	0.007	(2)	(2)	(2)	(2)
Temperature, F	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Suspended solids	10	5	(2)	(2)	5,000	2,500	100	100

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[1] Brackish water—dissolved solids more than 1,000 mg/l by definition 1963 census of manufacturers.

[2] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

[3] Zero, not detectable by test.

[4] Controlled by treatment for other constituents.

[5] No floating oil.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1). or APHA Standard methods for the examination of water and wastewater (5).

Part II. textile, lumber, paper and allied products

textile mill products (SIC 22)

Description of industry

The production of textiles is an ancient household art, but with the industrial revolution the production of textiles was rapidly changed to mills with mass production processes. At first, mills were located near rivers for water power. The mills also needed clear soft water for processing and therefore the textile industry developed in New England where both water power and good quality process water were available. Because much of their raw material (cotton) was produced in the Southeast, the textile plants gradually moved their cloth production and then their finishing process plants to the Southeast. By this time, mills were powered by coal or electricity so that many of them moved to communities which were located on the ridges. Many plants located on the Piedmont Plateau where the raw process water was soft but turbid. The technology of water treatment was sufficiently well developed that the turbidity was easily removed.

With time, the new synthetic fiber plants were located near the natural fiber plants. (The synthetic fiber production is part of the chemical industry.)

Natural fibers are spun, teased, and woven in the dry state, except for some stiffening of the warp; this latter process is known as sizing. The thread is run through the size which is dispersed in a highly concentrated water suspension. The natural fibers in the cloth are generally scoured to remove the sizing and natural waxes before bleaching and dyeing. Synthetic fibers which may be mixed with natural fibers in the cloth are also scoured, but this is incidental. The cloth is bleached before dyeing to obtain a more reproducible color each time a specific dye is used.

Water is used for scouring, bleaching, rinsing, and dyeing. The quality requirement for dyeing approaches that of distilled water.

In a very new development, water is used in place of a mechanical shuttle for weaving synthetic fibers. Except for dissolved gases and viscosity, the quality characteristics of this water have no significance.

Processes utilizing water

The sizing or stiffening of the warp fibers by starch or modified starches and cellulose compounds requires only small amounts of water for making the 10-percent suspensions, but because of the large number of mills and changes in size suspensions needed, the total water used is about 2 percent of the process water for cotton (SIC's 2211, 2221, 2231). No recycling is practiced.

The scouring of cotton and wool fibers and/or fabrics is widely practiced. While water quantity requirements are large, the quality requirements for specialized textile or fiber products are quite rigorous. Scouring is done at temperatures of 80 to 120 C and at pH 12 for cotton, but at much lower temperatures of 30 to 50 C and at pH 2 to 4 for wool. The water is not recycled in the scouring though large volumes of fabric may be scoured in one batch. The rinsing operation may be designed with counter current flow with use of the discharge for makeup water in scouring operation. The reuse of water in the textile industry is limited to the newest mills, for any reuse or conservation is not common in the older mills. The desizing of fabric is a cleaning operation that is similar to scouring in its water requirements. These operations involve 23 percent of the total process water for the cotton textile industry. Mercerizing of cotton is a specialized process which is becoming much less significant with the introduction of fiber blends and several cotton finishing plants have discontinued its use. In 1963, when the cotton textile industry figures were obtained, 13 percent of the cotton was mercerized but this required 28 percent of the process water.

The bleaching of textiles is done with either chlorine or hydrogen peroxide. Chlorine is generally used with cotton while hydrogen peroxide is used with blends containing synthetic fibers and with wool. When chlorine is used, the solution is generally adjusted to pH 9, but when hydrogen peroxide is used, the pH is adjusted in the range of 2.5 to 3.0. Rinsing of the bleached fibers or cloth requires a high quality water. Recent academic studies have suggested reuse of this water for preparing chlorine bleach, but the reuse is not now practiced (SIC 226). The bleaching operations in the cotton textile industry uses 20 percent of the process water.

TABLE V–6. Quality Characteristics of Surface Waters That Have Been Used by the Textile Industry (SIC 22)

[Unless otherwise indicated, units are mg/l and values are maximum. No one water will have all the maximum values shown.]

Characteristic	Concentration	Characteristic	Concentration
Iron (Fe)	0.3	Suspended solids	1,000
Manganese (Mn)	1.0	Hardness ($CaCO_3$)	120
Copper (Cu)	0.5	pH, units	6.0–8.0
Dissolved solids	150	Color, units	([1])

[1] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater, (5).

Water for dyeing operations has very high quality criteria, but no higher than those needed in the other processes. Cotton fibers (cloth) are dyed at moderately high pH values while wool is generally dyed at mildly acidic pH values. Synthetic fibers are dyed at various pH values depending upon the chemical character of the synthetic fiber. Water from the dyeing operations cannot be reused. The dyeing operations in the cotton textile industry use approximately 32 percent of the process water.

Significant indicators of water quality

Table V–6 shows the quality characteristics of raw waters that have been treated by existing processes to produce waters acceptable for the process waters used by the textile industry. Table V–7 shows the water quality requirements at point of use for the various processes within the textile industry. These processes are sizing, scouring, bleaching, and dyeing.

TABLE V–7. Quality Requirements of Water at Point of Use by the Textile Industry (SIC 22)

[Water quality prior to addition of substances used for internal conditioning. Unless otherwise indicated, units are mg/l and values that normally should not be exceeded.]

Characteristic	Sizing suspension	Scouring	Bleaching	Dyeing
Iron (Fe)	0.3	0.1	0.1	0.1
Manganese (Mn)	0.05	0.01	0.01	0.01
Copper (Cu)	0.05	0.01	0.01	0.01
Dissolved solids	100	100	100	100
Suspended solids	5	5	5	5
Hardness ($CaCO_3$)	25	25	25	25
pH, units:				
Cotton	6.5–10	9.0–10.5	2.5–10.5	7.5–10.0
Synthetics	6.5–10	3.0–10.5	([1])	6.5–7.5
Wool	6.5–10	3.0–5.0	2.5–5.0	3.5–6.0
Color, units	5	5	5	5

[1] Not applicable.

NOTE.—Application of the above values should be based upon analytical methods in Part 23 of the ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

Water treatment processes

Textile mills require clear process water. Clarification of surface water is practiced by all textile mills that do not purchase potable water or use ground water.

The early mills located on soft water supplies. As available soft water sites were filled, mills moved to hard water areas and practiced softening or bought city water. Batch softening or sequestering with EDTA or polyphosphates is now practiced in the critical processes even when a mill has a soft water supply. Demineralization is used by a few mills where color matching in dyeing operations is critical.

Chlorination is used to prevent slime on the piping but the concentration must be kept at a minimum since reducing agents are frequently required with sensitive dyes. Adjustment of the pH to a slightly alkaline value for enhancing the effectiveness of chlorine or chlorine dioxide in the removal of manganese creates a problem in meeting the pH requirements for some of the mill's processes.

Control of corrosion is very critical in the water distribution system because the corrosion products can stain cloth. Manganese removal may be necessary because loosened deposits of manganese dioxide which accumulate on copper water heating pipes (coils) may create disastrous results in rinsing operations.

lumber and wood products (SIC 24)

Description of industry and processes utilizing water

In general, the lumber industry collects logs from the forest and prepares them for use by sawing the log into various shapes. In the early years in this country, the logs were cut in the winter when the snow was on the ground to lubricate their transfer by dragging them overland to the river. The river transported the log to a millsite. The logs were frequently left in the water if they could be fenced off or driven into a back water to prevent them from going further downstream. While the log was floating, the water prevented the log from drying and cracking at the cut end.

Today, lumber may be transported to a mill which may not be near a river. If the logs accumulate, it is necessary to keep their ends moist to prevent cracking. This can be done by floating them in a pond or by spraying the log pile. The log is frequently debarked by water jets before cutting it into the desired shape.

Some lumber is treated with chemicals to reduce fire hazards, to retard insect invasion, or prevent "dry rot." These preservation processes use small volumes of water to prepare the solutions of chromates, cupric ions, aluminum ions, silicates, fluorides, arsenates, and pentachlorophenates. Some forest products are processed mechanically or chemically to make a variety of consumer products.

Significant indicators of water quality

There are few significant indicators of water quality for the lumber industry. The suspended solids should be less than 3 mm in diameter and the pH should preferably be between 5 and 9 to minimize corrosion of the equipment. Water used for transportation hardly qualifies as process water. Water used for spraying logs or *jet debarking* should be free of particles that clog the nozzles or jet openings. Such water is frequently recirculated. Water for preparation of solutions for treatment of the lumber should be reasonably free of turbidity and those ions which might react to form precipitates. Frequently, because of the highly toxic nature of these solutions, efforts are made to recycle as much solution as possible. Thus, makeup water is required to compensate for the portion of the solution forced into the lumber under pressure and then evaporated during seasoning.

Water treatment processes

For the lumber production phase only, straining may be required. Clarification may be practiced for water used in lumber preservation but this would be necessary on only a very small volume.

TABLE V–8. Quality Characteristics of Waters That Have Been Used by the Lumber Industry (SIC 24)

Characteristic	Value
Suspended solids	<3 mm, diameter.
pH, units	5 to 9.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

paper and allied products (SIC 26)

Description of industry

The pulp and paper industries are those described under the SIC Code Number 26. Since the principal product is paper, including paperboard, and the principal pulping processes are kraft and groundwood, the data given will be for these major processes. Specialty processes and products having unique water quality requirements should be considered as special cases.

Processes utilizing water

The manufacture of pulp and paper is highly dependent upon an abundant supply of water. The major process water uses are preparation of cooking and bleaching chemicals, washing, transportation of the pulp fibers to the next processing step, and formation of the pulp into the dry product.

Census data (7) for 1964 indicate that about 1,300 bgy of water were used by this industry and that about 74 percent or 990 billion gallons, required treatment prior to use. However, these data include water used for cooling, bearing lubrication, pulp seals, and other non-process requirements. If process water is defined as only water that contacts the product, the estimated usage is 500 bgy.

The process water required per ton of product is estimated in figures V–1 and V-2. Figure V–1 illustrates the typical Kraft process that is similar to the major pulping processes having chemical recovery. Wash water was estimated at 2,600 gal/ton for unbleached and 10,000 gal/ton for washing bleached pulp. Transportation of the pulp was estimated to require 4,000 gal/ton after each process. The amount of water recycled was based on the dilution required at each processing step and is much higher than the data given by the Bureau of the Census. Figure V–2 shows similar data for a typical mechanical pulping mill. A summary of the water used to produce finished paper products by the three major processes is given below.

Process water requirements, gallons per ton of product

	Intake [1]	Recycle	Consumption	Discharge
Mechanical Pulping	1,000	47,000	1,000	250
Unbleached chemical pulp and paper	7,000	115,000	1,000	6,000
Bleached chemical pulp and paper	20,000	250,000	1,000	19,000

[1] Does not include about 250 gallons per ton of water present in the woodchips.

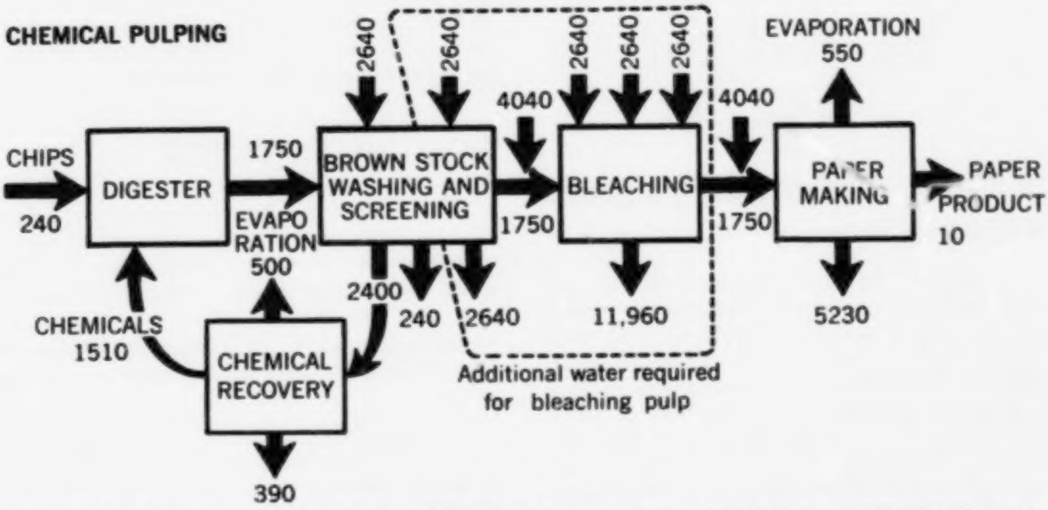
CHEMICAL PULPING
2640
2640
2640
2640
2640
EVAPORATION
550
4040
4040
CHIPS
240
DIGESTER
1750
BROWN STOCK WASHING AND SCREENING
EVAPO RATION
500
1750
BLEACHING
1750
PAPER MAKING
PAPER PRODUCT
10
2400
240
2640
11,960
5230
CHEMICALS
1510
CHEMICAL RECOVERY
390
Additional water required for bleaching pulp

Figure V-1—Pulp and paper industry: water intake, recycle, and discharge. (All data given as gallons of water per ton of product.)

Significant indicators of water quality

The quality characteristics of untreated surface waters used by the pulp and paper industry are given in table V–9. Treatment of the raw water should provide water to the process with the quality requirements described in table V–10. Process steam quality requirements are the same as those given under the steam generation and cooling water section.

In general, clarification, sedimentation, or filtration, either singly or in combination, and sometimes followed by softening, are employed in treating water for the pulp and paper industry.

TABLE V–9. Quality Characteristics of Surface Waters That Have Been Used by the Pulp and Paper Industry (SIC 26)

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristics	Mechanical pulping	Chemical pulp and paper	
		Unbleached	Bleached
Silica (SiO_2)	(1)	50	50
Aluminum (Al)	(1)	(1)	(1)
Iron (Fe)	2.6	2.6	2.6
Manganese (Mn)	(1)	(1)	(1)
Zinc (Zn)	(1)	(1)	(1)
Calcium (Ca)	(1)	(1)	(1)
Magnesium (Mg)	(1)	(1)	(1)
Sulfate (SO_4)	(1)	(1)	(1)
Chloride (Cl)	1,000	200	200
Dissolved solids	1,080	1,080	1,080
Suspended solids	(1)	(1)	(1)
Hardness ($CaCO_3$)	475	475	475
pH, units	4.6–9.4	4.6–9.4	4.6–9.4
Color, units	360	360	360
Temperature, F	(1)	(1)	95

[1] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

TABLE V–10. Quality Requirements of Water at Point of Use by the Pulp and Paper Industry (SIC 26)

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.]

Characteristics	Mechanical pulping	Chemical pulp and paper	
		Unbleached	Bleached
Silica (SiO_2)	(1)	50	50
Aluminum (Al)	(1)	(1)	(1)
Iron (Fe)	0.3	1.0	0.1
Manganese (Mn)	0.1	0.5	0.05
Zinc (Zn)	(1)	(1)	(1)
Calcium (Ca)	(1)	20	20
Magnesium (Mg)	(1)	12	12
Sulfate (SO_4)	(1)	(1)	(1)
Chloride (Cl)	1,000	200	200
Dissolved solids	(1)	(1)	(1)
Suspended solids	(1)	10[2]	10[2]
Hardness ($CaCO_3$)	(1)	100	100
pH, units	6–10	6–10	6–10
Color, units	30	30	10
Temperature, F	(1)	(1)	95

[1] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

[2] No gritty or color-producing solids.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

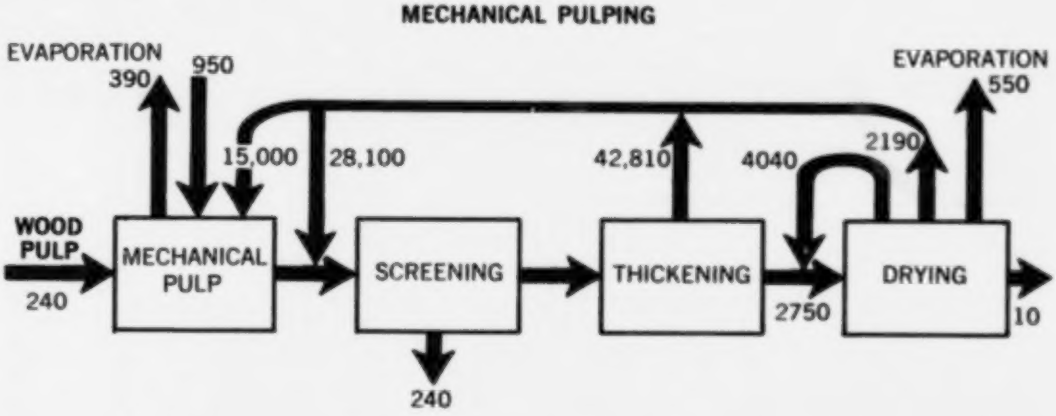

Figure V-2—Flow diagram showing water intake, recycling, and discharge in gallons per ton of product for pulp and paper making by a typically mechanical pulping mill.

Part III.

chemical and allied products (SIC 28)

Description of industry

Task force III was concerned with the water quality criteria for the chemical and allied products industries. This is in accordance with the 1963 census of manufacturers water use in manufacturing SIC's 2812–15, –18, –19, –21, –22, –34, –41, –51, –61, 07, –71, –92. These waters are for process use only and do not include either boiler feed or cooling waters.

Processes utilizing water

The subject industries and their process water intake are shown in table V–11. No breakdown has been made of the use by each process within a given 4-digit SIC coding.

Significant indicators of water quality

The number and diversity of manufacturing facilities in the chemical and allied products industries and their wide geographic location in the United States are such that the surface waters which they use will vary widely in chemical constituents. Water quality characteristics for raw water supplies that have been used to provide water for process use for each industry are listed in table V–12. Table V–13 gives water quality requirements at point of use by the various industries.

Water treatment processes

The cost of water treatment is a very small part of the overall cost of manufacturing in the chemical industry. The normal water purification consists of clarification (coagulation, sedimentation, filtration). This may be supplemented by softening, cold lime, lime soda, zeolite, and demineralization, singly or in combination to provide the quality required from any source of raw surface water. The technical skills available in the chemical industry are of such nature that proper water treatment can be provided to produce water of satisfactory quality for manufacturing processes, under all conditions.

TABLE V–13.

[Unless otherwise indicated, units are mg/l and valu

Characteristic	(1) SIC 2812 alkalies and chlorine	(2) SIC 2815 interm. coal tar products
Silica (SiO_2)	(1)	(2)
Iron (Fe)	0.1	(2)
Manganese (Mn)	0.1	(2)
Calcium (Ca)	(1)	(2)
Magnesium (Mg)	(1)	(2)
Bicarbonate (HCO_3)	(1)	(2)
Sulfate (SO_4)	(1)	(2)
Chloride (Cl)	(1)	(2)
Nitrate (NO_3)	(1)	(2)
Total solids	(1)	(2)
Hardness ($CaCO_3$)	(1)	(2)
pH	(1)	(2)
Color	(1)	(2)
Suspended solids	(1)	(2)
Odor	(1)	(2)
5-day BOD (O_2)	(1)	(2)
COD (O_2)	(1)	(2)
Dissolved oxygen (O_2)	(1)	(2)
Alkalinity ($CaCO_3$)	(1)	(2)

[1] Potable water.

[2] Accepted as received (if meeting total solids

TABLE V–11. Process Water Intake by Chemical and Allied Product Industries With Total Water Intake of 20 or More bgy During 1964

SIC	Industry group and industry	Process water intake	
		Bgy	Percent
2812	Alkalies and chlorine	16	2.8
2815	Intermediate coal tar products	9	1.6
2818	Organic chemicals, n.e.c.[1]	314	55.5
2819	Inorganic chemicals, n.e.c.[1]	74	13.3
2821	Plastic materials and resins	25	4.4
2822	Synthetic rubber	11	2.0
2834	Pharmaceutical preparations	3	0.5
2841	Soaps and other detergents	2	0.4
2851	Paints and allied products	1	0.2
2861	Gum and wood chemicals	2	0.4
2871	Fertilizers	32	5.6
2892	Explosives	2	0.4
	Subtotal	491	87.1
-----	Nonlisted industries[2]	73	12.9
28	Chemicals and allied products	564	100.0

[1] Not elsewhere classified.

[2] Although the industries selected for study probably determine the range in values of the various quality criteria for process waters for chemical and allied products, it is noted that 3 industries (SIC 2823, Cellulosic Man-Made Fibers; SIC 2824, Organic Fibers Noncellulosic; and SIC 2891, Glue and Gelatin) use 23, 8, and 6 bgy, which is more than several of the industries under consideration.

TABLE V–12. Quality Characteristics of Surface Waters That Have Been Used by the Chemical and Allied Products Industry (SIC 28)

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristic	Concentration	Characteristic	Concentration
Silica (SiO_2)	(1)	Suspended solids	10,000
Iron (Fe)	5	Hardness ($CaCO_3$)	1,000
Manganese (Mn)	2	Alkalinity ($CaCO_3$)	500
Calcium (Ca)	200	pH, units	5.5–9.0
Magnesium (Mg)	100	Color	500
Ammonia (NH_3)	(1)	Odor	(1)
Bicarbonate (HCO_3)	600	BOD (O_2)	(1)
Sulfate (SO_4)	850	COD (O_2)	(1)
Chloride (Cl)	500	Temperature	(1)
Dissolved solids	2,500	DO (O_2)	(1)

[1] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

Quality Requirements of Water at Point of Use by Chemical and Allied Products Industry (SIC 28)

that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.]

(3) SIC 2818 organic chemicals	(4) SIC 2819 inorganic chemicals	(5) SIC 2821 plastic materials and polymers	(6) SIC 2822 synthetic rubber	(7) SIC 2834 drugs and pharmaceutical preparations[1]	(8) SIC 2841 soap and other detergents	(9) SIC 2851 paints and allied products	(10) SIC 2861 gums and wood chemicals	(11) SIC 2871 fertilizers	(12) SIC 2892 explosives
(1)	(1)	(1)	(1)	(1)	(1)	(1)	50	(1)	(1)
0.1	(1)	(1)	0.1	(1)	(1)	(1)	0.3	(1)	(1)
0.1	(1)	(1)	0.1	(1)	(1)	(1)	0.2	(1)	(1)
68	(1)	(1)	80	(1)	(1)	(1)	100	(1)	(1)
19	(1)	(1)	36	(1)	(1)	(1)	50	(1)	(1)
128	(1)	(1)		(1)	(1)	(1)	250	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	100	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	500	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	5	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	1,000	(1)	(1)
250	(1)	(1)	350	(1)	(1)	(1)	900	(1)	(1)
6.5–8.7	(1)	(1)	6.2–8.3	(1)	(1)	(1)	6.5–8.0	(1)	(1)
(1)	(1)	(1)	20	(1)	(1)	(1)	20	(1)	(1)
(1)	(1)	(1)	5	(1)	(1)	(1)	30	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
125	(1)	(1)	150	(1)	(1)	(1)	200	(1)	(1)

or other limiting values); has never been a problem at concentrations encountered.

[2] No practical limit—any concentration can be handled.

[3] Controlled by treatment for other constituents.

Part IV.

petroleum and coal products (SIC 29)

Description of industry

Today's oil industry is engaged in finding oil, getting it out of the ground, transporting it, making it into useful products, and marketing and delivering these products to consumers.

The principal withdrawal of water is for refining. Other operations such as transportation of crude oil and products and marketing rely on it, but do not use significant amounts of water. Some water is used in the producing branch for drilling wells and operation of natural gasoline plants, but the amount is insignificant in relation to that used in the refining process.

Processes utilizing water

Separation, conversion, and treating operations use large quantities of water. The 1963 Census of Manufacturers (7) indicates a gross water use of about 6,100 bgy in 1964. However, the water intake to refineries for this same period shows that only 1,400 billion gallons was taken in as supply. This indicates substantial reuse of water. Ninety-two percent of those reporting indicated that they were reusing water.

Of the total water intake, 87 percent is used for cooling purposes, 7 percent for boiler feed and sanitary purposes and only 6 percent for processing. Process water uses include desalting, washing, barometric condensing, and product transportation.

One use of process water in refining operations is the removal of brine from crude oil to prevent a buildup of solids in the processing equipment and to prevent hydrochloric acid corrosion problems. Water quality for this operation is not critical. Actually, waste water is frequently used for this purpose because it provides a means whereby certain impurities, such as phenols, can be eliminated from the waste water.

Most refinery products must be treated to improve color, odor, or stability, or to remove sulfur, gums, or other corrosive substances before the product is marketable. Caustic, acid, and clay treating, various sweetening operations, and solvent extraction are some of the methods used. Water is used in these operations for makeup of caustic and acid solutions and for product washing. Lubricating oils are treated with acids, by contact with or percolation through clay, or by solvent extraction methods. Both steam and water are used to recover solvents and to clean the filter clays.

Numerous operations use barometric condensers for creating low pressure conditions in fractional distillation. The condenser water contacts overhead products thereby dissolving pollutants. For this reason, barometric condensers are being replaced by surface condensers in many cases.

Water under high pressure from cutting heads is used to reduce the size of coke particles so that they can be removed from the coking chambers. Frequently, coke fines are removed by clarification and the water reused. Wax manufacturing processes sometimes use water as a transporting medium and the process water is then generally recirculated.

Specific indicators of water quality

For process water requirements, refiners use treated or untreated cooling water, public water supplies, or ground water. Of the total water intake by refineries, about 84 percent is secured from surface supplies, 7 percent from ground water, and the remaining 9 percent from public water supplies.

The primary treatment of water for process use is for suspended solids and turbidity removal. Some washing operations are normally provided with water of about 10 mg/l or less suspended solids. However, there are many refineries that do not treat process water.

The quality characteristics of surface waters that have been treated by existing processes to produce waters acceptable for process use are given in table V–14. The quality requirements at point of use are given in table V–15.

TABLE V–14. Quality Characteristics of Surface Waters That Have Been Used by the Petroleum Industry (SIC 29)

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristic	Concentration	Characteristic	Concentration
Silica (SiO_2)	50	Chloride (Cl)	1,600
Iron (Fe)	15	Fluoride (F)	1.2
Calcium (Ca)	220	Nitrate (NO_3)	8
Magnesium (Mg)	85	Dissolved solids	3,500
Total sodium and potassium (Na, K)	230	Suspended solids	5,000
Bicarbonate (HCO_3)	480	Hardness ($CaCO_3$)	900
Sulfate (SO_4)	570	Color, units	25
		pH, units	6.0-9.0

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

TABLE V–15. Quality Requirements of Water at Point of Use for Petroleum Industry (SIC 29)

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.]

Characteristic	Concentration	Characteristic	Concentration
Silica (SiO_2)	(1)	Nitrate (NO_3)	(1)
Iron (Fe)	1	Dissolved solids	1,000
Calcium (Ca)	75	Suspended solids	10
Magnesium (Mg)	30	Hardness ($CaCO_3$)	350
Total sodium and potassium (Na, K)	(1)	Noncarbonate hardness ($CaCO_3$)	70
Bicarbonate (HCO_3)	(1)	Color, units	(1)
Sulfate (SO_4)	(1)	pH, units	6.0-9.0
Chloride (Cl)	300		
Fluoride (F)	(1)		

[1] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater, (5).

Part V.
primary metals industries (SIC 33)

Description of industry

The industries which are incorporated within the category of primary metals in this report are those which are included in the Standard Industrial Classification (SIC) Manual (6) as industry group 33. This industrial group is defined as those "establishments engaged in the smelting and refining of ferrous and nonferrous metals from ore, pig, or scrap; in the rolling, drawing, and alloying of ferrous and nonferrous metals; in the manufacture of castings, forgings, and other basic products of ferrous and nonferrous metals; and in the manufacture of nails, spikes, and insulated wire and cable. The major group also includes the production of coke."

This section defines, as accurately as possible at this time, the process water quality requirements for the industry.

Process water utilization by the primary metals industry as given in the Bureau of the Census (7) is summarized by the following table.

Process water utilization

Industry	SIC No.	Process water used, 1964 (billion gals.)
Iron and steel production	331	885
Iron and steel foundries	332	12
Copper industry	3331, 3351	36
Aluminum industry	3334, 3352	20
All other primary metal industries	————	43
Total process water, primary metals	33	996

The production of iron and steel utilized almost 90 percent of all process water used by the industry. For this reason, water quality requirements have only been included for this segment of the industry.

Processes utilizing water

The iron and steel industry as defined for this report includes pig iron production, coke production, steelmaking, rolling operations, and those finishing operations common to steel mills, such as, cold reduction, tin plating, and galvanizing. Although many steel companies operate mines for ore and coal, ore beneficiation plants, coal cleaning plants, and fabricating plants for a variety of specialty steel products, these are excluded from this report.

Most of the iron and steel making facilities in the United States are centered in integrated plants. These have generally been located in the midwest and east where major water sources are available. A few mills have been built in water-short areas because of economic advantages which outweighed the increased cost of recirculating water. The major processes involved in the manufacture of steel all require process water, some in several ways. The succeeding paragraphs present a brief description of the process and the process use of water.

The production of coke involves the heating of coal in the absence of air in order to rid the coal of tar and other volatile products. Process water is used in the direct cooling of the incandescent coke after removal from the coke oven in a process called coke quenching. This quenching process is nothing more than dousing the coke with copious amounts of water.

Pig iron production is accomplished in the blast furnace. Process water is used to cool or quench the slag when it is removed from the furnace. The major use of process water in the blast furnace is for gas cleaning in wet scrubbers. Steel is manufactured in open hearth or basic oxygen furnaces. Process water may be used in gas cleaners for either of these furnaces.

The major products of the steelmaking processes are ingots. Ingots, after temperature conditioning, are rolled into blooms, slabs, or billets depending upon the final product desired. These shapes are referred to as semifinished steel. Water is used for cooling and lubricating the rolls. These semifinished products are used in finishing mills to produce a variety of products such as plates, rails, structural shapes, bars, wire, tubes, and hot strip. Hot strip is a major product and the manufacturing process for this item will be briefly described.

The continuous hot strip mill receives temperature conditioned slabs from reheating furnaces. Oxide scale is loosened from the slabs by mechanical action and removed by high pressure jets of water prior to a rough rolling stand, which produces a section that can be further reduced by the finishing stand of rollers. A second scale breaker and series of high-pressure water sprays precede this stand of rolls in which final size reductions are made. Cooling water is used after rolling for cooling the strip prior to coiling. Most hot-rolled strip is pickled by passing the strip through solutions of mineral acids and inhibitors. The strip is then rinsed with water.

Much hot-rolled strip is further reduced in thickness in cold rolls in which the heat generated by working the metal is dissipated by water sprays. Palm oil or synthetic oils are added to the water for lubrication. After cold reduction, the strip is often cleaned by using an alkaline wash and rinse.

Tin plate is made from cold-rolled strip by either an electrolytic or hot-dip process, most commonly by the former. The electrolytic process consists of cleaning the strip using alkaline cleaners, rinsing with water, light pickling, rinsing, plating, rinsing, heat treating, cooling with water (quenching), drying, and coating with oil. The galvanizing or coating of steel strip with various other products is carried out basically by the same general scheme as tinning.

The volume of water used in the manufacturing of steel is a variable which depends on the quantity and quality of the available supply. The quantity presently being used varies from a minimum of about 1,500 gal/ton of product, where water is reused intensively, to about 65,000 gal/ton, where water is used on only a once through basis. Both of these figures include total water utilized, not just process water. These figures contrast the range of water intake between plants in areas having: (1) extremely limited, and (2) almost unlimited water supplies.

The only definitive information available to the task force on the amount of process water required as compared with other water uses was found in the census of manufacturers (7). The following is a summary of this information for 1964 for the steel industry (SIC 331).

Water use:	Volume, bgy
Intake water	4,051
Process water	885
Cooling	3,008
Boiler feed, etc.	159

This tabulation indicates that only 22 percent of the water taken into a steel plant is termed process water. Representatives of the industry have indicated that process water may account for as much as 30 to 40 percent of the total water intake.

Recycling of water is receiving much attention from the industry as a method to reduce water utilization, reduce stream pollution, and minimize the cost of controlling this pollution. Although individual plants within the iron and steel industry have been practicing reuse of water to varying degrees for some years, the major changes are yet to come. According to the Census of Manufactures, the gross water used in the industry in 1964 was approximately 5,800 billion gallons. This gross water use when compared with a water intake of about 4,000 billion gallons indicates that 1,800 billion gallons were reused. This quantity reflects total water reuse not just of process water. The consumption of water by the industry amounted to approximately 240 billion gallons in 1964. No corresponding calculation may be made at this time for process water only because no data on process water discharge are available.

Significant indicators of water quality

The water quality indicators which will be considered are settleable, suspended, and dissolved solids, acidity and alkalinity, hardness, pH, chlorides, dissolved oxygen, temperature, oil, and floating material. In the judgment of the task force, this short list incudes those process water qualities that are considered important to the industry.

The quality of surface waters that are being utilized by the iron and steel industry varies considerably from plant to plant. Ranges of values for the selected quality characteristics for existing supplies are listed in table V–16. The quality of the water available has been much less important than the quantity in determining where a steel mill should be built and even severe limitations on water availability have not precluded the building of new mills where the controlling economic factors were considered favorable.

TABLE V–16. Quality Characteristics of Surface Waters That Have Been Used by the Iron and Steel Industry (SIC 33)

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristics	Concentrations	Characteristics	Concentrations
Settleable solids	350	Hardness ($CaCO_3$)	1,000
Suspended solids	3,000	pH, units	3–9
Dissolved solids	1,500	Chloride (Cl)	500
Acidity, ($CaCO_3$)	75	Temperature, F	100
Alkalinity ($CaCO_3$)	200	Organics, carbon tetrachloride extractables	30

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

The desired quality of water for various process use in the iron and steel industry is difficult to define. For a few processes, using relatively small quantities of water, limits on some constituents are known. For most of the process water used, however, only a few of the water quality characteristics have been recognized as a cause of operational problems. For the other characteristics or properties neither the technological nor economical limits are known.

Water treatment processes

Most integrated steel plants have two or more process water systems. One system is the general plant water supply. It receives only mechanical skimming and straining for control of floating and suspended materials which could harm pumps and possibly internal conditioning. This water is used for such diverse tasks as coke quench, slag quench, gas cleaning, and in the hot rolling operations. For some of these operations, many mills use effluent from another process or recycle water in the same process and the water might actually be of very poor quality. However, the only limits for these process uses which could be established based on present knowledge are those listed in table V–17.

The other process waters used by the steel industry comprise only 2 to 5 percent of the total volume but often require considerably improved quality. Almost universally, one of these two improved supplies is clarified while the second is, in addition, either softened or demineralized.

The clarified water is usually a coagulated, settled, and filtered supply that is either treated by the steel company or purchased from a municipality. The use for this water is mainly in the cold rolling or reduction mill where surface properties of the product are particularly important.

The softened or demineralized water is required for rinse waters following some pickling and cleansing operations. The more particular processes from a water quality point of view are the coating operations such as tin plating, galvanizing, organic coating, etc. Some plants use softened and others demineralized water for identical purposes. The quality limits desired for these two types of water, softened and demineralized, are given in table V–17. The quantity of these waters required is less than 1 percent of the total process water supply.

TABLE V–17. Quality Requirements of Water at Point of Use for the Iron and Steel Industry (SIC 33)

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.]

Characteristics	Quenching, hot rolling, gas cleaning	Cold rolling	Selected rinse waters	
			Softened	Demineralized
Settleable solids	100	(2)	(2)	(5)
Suspended solids	(1)	10	(2)	(5)
Dissolved solids	(1)	(1)	(1)	(5)
Alkalinity ($CaCO_3$)	(3)	(3)	(3)	(5)
Hardness ($CaCO_3$)	(3)	(3)	100	(5)
pH, units	5–9	5–9	6–9	(5)
Chloride (Cl)	(1)	(1)	(1)	(5)
Dissolved oxygen (O_2)	(4)	(4)	(4)	(4)
Temperature, F	100	100	100	100
Oil	(1)	(2)	(2)	(2)
Floating material	(1)	(2)	(2)	(2)

---

[1] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

[2] Zero, not detectable by test.

[3] Controlled by treatment for other constituents.

[4] Minimum to maintain aerobic conditions.

[5] Concentration not known.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater, (5).

Part VI.

food and kindred products and leather and leather products (SIC's 20 and 31)

food canning industry (SIC's 2032 and 2033)

Description of industry

Nearly 2,000 canneries make up the Nation's canning industry. These are located in 49 of the 50 States, Puerto Rico, and the Virgin Islands. These plants produce all of the basic canned foods —vegetables, fruits and fruit juices, milk, meat, seafoods, soups, and infant foods, as well as numerous specialties and combinations. More than 1,200 different canned items and combinations are made available from the production of these canneries. The 1965 pack of canned foods was more than 765 million cases containing over 27 billion tin and glass containers divided among these main categories: seasonal vegetables, 227 million cases; fruits, 124 million cases; juices, 114 million cases; milk, 44 million cases; fish, 3 million cases; canned meat, 46 million cases.

Processes utilizing water

One of the most important operations in commercial canning is thorough cleaning of the raw foods. The procedures of cleaning vary with the nature of the food; but all raw foods must be freed of adhering soil, dried juices, insects, and chemical residues. This is accomplished by subjecting the raw foods to high-pressure water sprays while being conveyed on moving belts or passed through revolving screens. The product wash water may be fresh or reclaimed from an in-plant operation, but it must be of potable quality.

Washed raw products are transported to and from the various operations by means of belts, flumes, and pumping systems. This is a major use of water. Although the fresh water makeup must be of potable quality, recirculation is practiced to reduce water intake. Chlorination is used to maintain recycled waters in a sanitary condition.

A third major use of water is for rinsing chemically peeled fruits and vegetables to remove excess peel and caustic residue. Water of potable quality must be used.

Green vegetables are immersed in hot water or exposed to live steam in blanching operations to inactivate enzymes and to wilt leafy vegetables to facilitate their filling into cans or jars. The

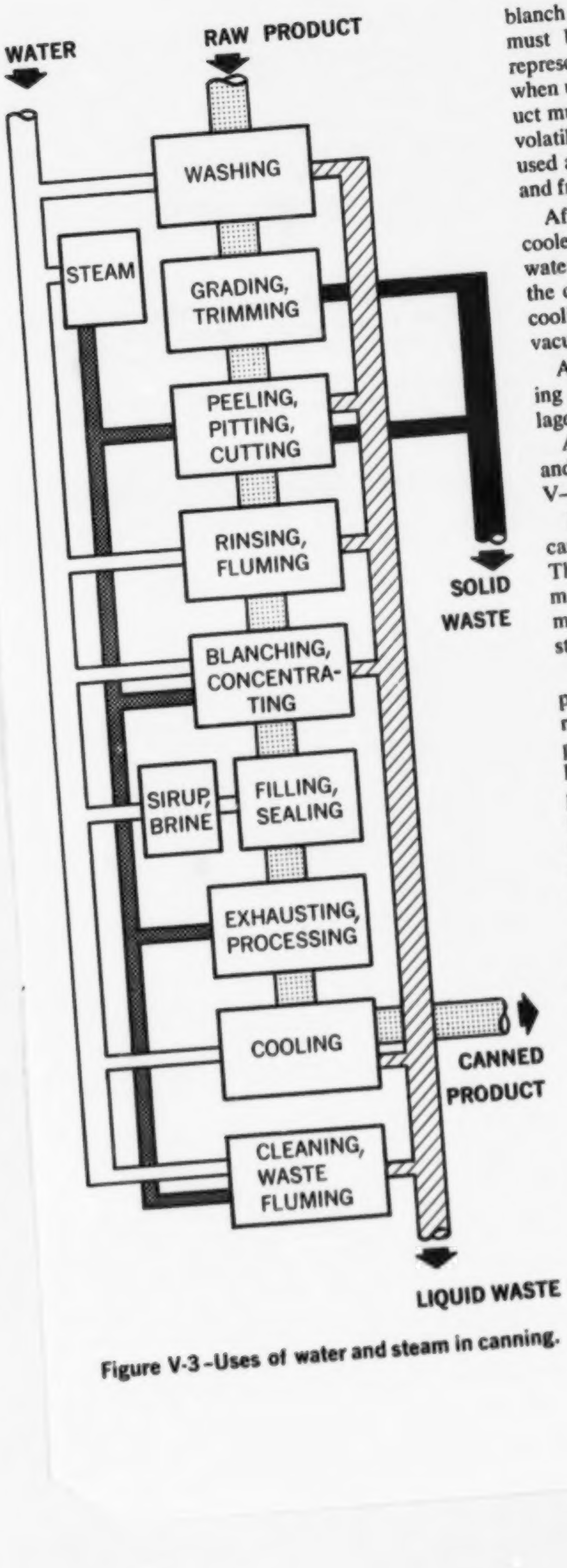
WATER
RAW PRODUCT
WASHING
STEAM
GRADING, TRIMMING
PEELING, PITTING, CUTTING
RINSING, FLUMING
SOLID WASTE
BLANCHING, CONCENTRATING
SIRUP, BRINE
FILLING, SEALING
EXHAUSTING, PROCESSING
COOLING
CANNED PRODUCT
CLEANING, WASTE FLUMING
LIQUID WASTE

Figure V-3 – Uses of water and steam in canning.

blanch waters are recirculated, but makeup waters must be of potable quality. Steam generation, representing about 15 percent of water intake, when used for blanching or injection into the product must be produced from potable waters, free of volatile or toxic compounds. Syrup, brine, or water used as a packing medium must be of high quality and free of chlorine.

After heat processing, the cans or jars are cooled with large volumes of potable water. This water must be chlorinated to prevent spoilage of the canned foods, by microorganisms in case that cooling water is aspirated during formation of a vacuum in the can.

A final significant use of water is for transporting from the cannery, the inedible product, spillage, and trimmings that are discarded as waste.

A flow sheet showing the various uses of water and origin of waste streams is attached as figure V–3.

Most fruit and vegetable canning, as opposed to canning of specialty products, is highly seasonal. The demand for water may vary 100 fold among months of the year. The water-demand variation may be several fold even for plants that pack substantial quantities of nonseasonal items.

The gross quantities of water used per ton of product vary widely among products, among canneries, and among years in the same cannery. The proportion of gross water supplied by recirculation has increased over the years and the trend is expected to continue. A tendency has been noted to use more water per ton of product as the proportion of recirculated water increases. The consumptive use of water is also expected to increase with recirculation.

The following tabulation gives the fate of gross water intake as based on the 1963 census of manufacturers (7) for canning plants having an annual water intake of 20 or more million gallons.

Item	Water quantity (bgy[1])	Percent of intake quantity
Intake	48	100
Reuse	18	37
Consumption	4	8
Discharge	44	92

A breakdown of the quantities and percentages of the total water used in the various process operations based on data from the National Canners Association is as follows:

In-plant use	Water quantity (bgy)	Percent of total use
Raw product washing	9.9	15
Product transport [1]	6.6	10
Product preparation [2]	6.6	10
Incorporation in product [3]	4.0	6
Steam and water sterilization of containers	9.9	15
Container cooling	23.7	36
Plant cleanup	5.3	8

[1] Fluming and pumping of raw product.
[2] Blanching, heating, and soaking of product.
[3] Preparation of syrups and brines which enter the container.

Significant indicators of water quality

Of the 48 billion gallons of water intake for the two groups (canned and cured seafoods and canned fruits and vegetables), 24 billion gallons were drawn from public water supplies and more than 20 billion gallons from ground sources. Approximately 4 billion gallons came from surface water supplies.

The quality of raw surface waters for use in the food canning industry should be that prescribed by the NTA Subcommittee on Water Quality Criteria for Public Water Supplies, in this volume.

Table V–18 has been prepared to indicate the quality characteristics of raw waters that are now being treated for use as process waters in food canning plants. The values are drawn from limited data and the procedures and costs of treating the raw waters are not available at this time. The values given are not intended to imply that better quality waters are not desirable or that poorer quality waters could not be used in specific cases. Significant water quality requirements for water at point of use are given in table V–19.

TABLE V–18. Quality Characteristics of Surface Waters That Have Been Used by the Food Canning Industry

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded.]

Characteristic	Concentration	Characteristic	Concentration
Alkalinity ($CaCO_3$)	300	Fluoride (F)	(1)
pH, units	8.5	Organics: Carbon chloroform extract	0.3
Hardness ($CaCO_3$)	310	Chemical oxygen demand (O_2)	(2)
Calcium (Ca)	120	Odor, threshold number	(1)
Chlorides (Cl)	300	Taste, threshold number	(1)
Sulfates (SO_4)	250	Color, units	5
Iron (Fe)	0.4	Dissolved solids	550
Manganese (Mn)	0.2	Suspended solids	12
Silica (SiO_2), dissolved	50	Coliform, count/100 ml	(1)
Phenols	(1)		
Nitrate (NO_3)	45		
Nitrite (NO_2)	(3)		

[1] As specified by NTA Subcommittee on Water Quality Criteria for Public Water Supplies, in this volume.

[2] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

[3] Zero, not detectable by test.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater, (5).

TABLE V–19. Quality Requirements of Water at Point of Use by the Canned, Dried, and Frozen Fruits and Vegetables Industry

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.]

Characteristic	Canned specialities (SIC 2032) Canned fruits, vegetables, etc. (SIC 2033) Dried fruits and vegetables (SIC 2032) Frozen fruits and vegetables (SIC 2037)
Acidity (H_2SO_4)	0
Alkalinity ($CaCO_3$)	250
pH, units	6.5–8.5
Hardness ($CaCO_3$)	250
Calcium (Ca)	100
Chlorides (Cl)	250
Sulfates (SO_4)	250
Iron (Fe)	0.2
Manganese (Mn)	0.2
Chlorine (Cl)	(1)
Fluorides (F)	1 [2]
Silica (SiO_2)	50
Phenols	(3, 4)
Nitrates (NO_3)	10 [2]
Nitrites (NO_2)	(3)
Organics:	
Carbon tetrachloride	0.2 [5]
Odor, threshold number	(6)
Taste, threshold number	(6)
Turbidity	(6)
Color, units	5
Dissolved solids	500
Suspended solids	10
Coliform, count/100 ml	(6)
Total bacteria, count/100 ml	(7)

[1] Process waters for food canning are purposely chlorinated to a selected, uniform level. An unchlorinated supply must be available for preparation of canning syrups.

[2] Waters used in the processing and formulation of foods for babies should be low in fluorides concentration. Because high nitrate intake is alleged to be involved in infant illnesses, the concentration of nitrates in waters used for processing baby foods should be low.

[3] Zero, not detectable by test.

[4] Because chlorination of food processing waters is a desirable and widespread practice, the phenol content of intake waters must be considered. Phenol and chlorine in water can react to form chlorophenol, which even in trace amounts can impart a medicinal off flavor to foods.

[5] Maximum permissible concentration may be lower depending on type of substance and its effect on odor and taste.

[6] As required by USPHS drinking water standards, 1962 (8).

[7] The total bacterial count must be considered as a quality requirement for waters used in certain food processing operations. Other than esthetic considerations, high bacterial concentration in waters coming in contact with frozen foods may significantly increase the count per gram for the food. Waters used to cool heat-sterilized cans or jars of food must be low in total count for bacteria to prevent serious spoilage due to aspiration of organisms through container seams. Chlorination is widely practiced to assure low bacterial counts on container cooling waters.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater, (5).

Water treatment processes

Where used by the food canning industry, surface waters will require treatment before use as process waters. Usually, this treatment involves coagulation, sedimentation, filtration, and disinfection. More extensive treatment may be required for those waters incorporated in the product.

Container cooling waters are routinely treated by heavy chlorination to render them free of significant types of bacteria. Waters used for washing and transporting raw foods are generally chlorinated particularly if all or a portion of the water is recirculated. In some cases, waters in which vegetables are blanched, may require treatment to reduce hardness.

bottled and canned soft drinks (SIC 2086)

Description of industry

While essentially local in nature, the soft drink industry is national in character because it operates on a franchise system. A soft drink franchise grants the right to produce and distribute a specific beverage in a certain area.

There has been a marked reduction in the number of producing plants—from 5,469 in 1954 with a production of 1,176,674,000 cases to 3,619 in 1965 with a production of 2,104,282,000 cases.[1]

It is obvious that numerous small plants have been discontinued as producing units. This trend is likely to continue in future years.

Processes utilizing water

In the production of soft drinks, water is used not only in the finished product itself but also for the following purposes:

—Washing containers.
—Cleaning production equipment.
—Cooling refrigeration and air compressors.
—Plant clean up.
—Truck washing.
—Sanitary purposes (restrooms and showers).
—Lawn watering.
—Low-pressure heating boilers.
—Air conditioning.

Water quantity utilized by each process is estimated as:

Intake—approximately 25 bgy.
Recycle—6 bgy.
Consumption—3 bgy.
Discharge—22 bgy.

A comprehensive survey of the quantity of water intake and reuse has not been made. The 1963 census of manufacturers (7) lists the total water intake of bottled and canned soft drinks as 6 billion gallons. However, this quantity is the amount used by only 114 of the largest plants whose water intake was 20 or more million gallons per year. This is less than 3 percent of the total number of plants. The 1963 census does not give the total quantity of beverage produced by the 114 plants, so the water usage data cannot be extrapolated to give an estimate of the total industry usage.

The figure of 25 billion gallons intake is based upon production of 2.1 billion cases per year and an average of 12 gallons of water used per case. The figure of 12 gallons per case came from the limited data now available.

The 1963 census of manufacturers (7) lists the gross water usage, including recycle, as 8 billion gallons and total water intake as 6 billion gallons. There is no similar data for the entire industry. However, the reuse of water within the industry has for some years increased and is still increasing as the older and smaller plants are replaced by new and larger plants which use recirculating rather than once through cooling water equipment, modern bottle washers which use less water per case washed than does older equipment, and other water reuse devices.

The consumption figure of 3 billion gallons is based upon the water content of the total quantity of beverage produced in 1965.

The discharge figure of 22 billion gallons is the difference between the estimated 25 billion gallons of intake and the 3 billion gallons of product water.

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[1] A case is defined as 24 bottles containing 8 ounces of beverage. In the above figures, bottles larger or smaller than 8 ounces have been converted to 8-ounce equivalents. Data obtained from National Soft Drink Association, 1128 16th Street, NW, Washington, D.C.

Significant indicators of water quality

Water which is mixed with flavoring materials to produce the final product must be potable. Likewise, potable water is needed for washing fillers, syrup lines, and other product handling equipment. The water used for washing product containers must also be potable.

Although other water uses do not require potability, it has not been customary to use non-potable water for any purpose in a soft drink plant.

The water which becomes a part of the final product must not only be potable, but must also contain no substances which will alter the taste, appearance, or shelf life of the beverage. Because beverages are made from many different syrup bases, the concentration and type of substances which affect taste, or other characteristics, are not the same for all beverages. For this reason a single standard cannot apply to all types of soft drinks. This is the conclusion reached by the water treating committee of the Society of Soft Drink Technologists after conducting a survey of the water composition required by the various franchise companies.

The majority of plants use only water from a public supply. Some use water from private wells. None use water directly from surface sources. Hence, the quality characteristics for intake water are the same as quality requirements for potable water.

Uniformity of water composition is most desirable. Control of in-plant processing is difficult when the composition of the water varies from day to day. Surface waters which are subject to heavy biological growths or heavy pollution with organic chemicals are also difficult to process.

Except for process water, most public water supplies are suitable without external treatment for all other usages. Occasionally, cation exchangers are used to soften bottle washing, cooling, and boiler feed water, but internal conditioning is used in most plants for scale and corrosion control.

Water treatment processes involved

There are few, if any, public water supplies which are suitable as product water without any in-plant processing whatsoever. Almost 100 percent of the bottling plants have a sand filter and an activated carbon purifier. About 80 percent of the plants also coagulate and super-chlorinate the water preceding sand filtration and carbon purification. When the total alkalinity of the intake water is too high, lime is used to precipitate the alkaline salts.

There are very few bottling plants whose intake water is so highly mineralized that the brackish taste affects soft drinks. This is due to several facts: flavoring components in soft drinks mask the taste of salts so that many waters which taste brackish do not alter the taste of soft drinks; towns with highly mineralized water supplies are avoided as locations for bottling plants or suitable private supplies are used.

TABLE V–20. Quality Requirements of Water at Point of Use by the Soft Drink Industry (SIC 2086)

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.]

Characteristic	Concentration	Characteristic	Concentration
Alkalinity ($CaCO_3$)	85	Fluoride (F)	(3)
pH, units	(1)	Total dissolved solids	(1)
Hardness ($CaCO_3$)	(1)	Organics, CCE	0.2 [4]
Chlorides (Cl)	500 [2]	Coliform bacteria	(3)
Sulfates (SO_4)	500 [2]	Color, units	10 [4]
Iron (Fe)	0.3	Taste	(4, 5)
Manganese (Mn)	0.05	Odor	(4, 5)

[1] Controlled by treatment for other constituents.

[2] If present with equivalent quantities of Mg and Ca as sulfates and chlorides, the permissible limit may be somewhat below 500 mg/l.

[3] Not greater than USPHS Drinking Water Standards.

[4] In general, public water supplies are coagulated, chlorinated, and filtered through sand and granular activated carbon to insure very low organic control and freedom from taste and odor.

[5] Zero, not detectable by test.

NOTE.—Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

tanning industry
(SIC 3111)

Description of industry

The tanning-leather industry is many industries as each type of leather constitutes a different process. Basically there are only three or four types of tannage (vegetable, mineral, combination of vegetable-mineral, and syntans) but many finishing processes.

Processes utilizing water

Water is used in all processes of storage, sorting, trimming, soaking, green fleshing, unhairing, neutralizing, bating, pickling, tanning, retanning, fat-liquoring, drying and finishing of the hides. It is an essential factor in each process. The chemical composition of the water is considered critical in obtaining the desired quality of leather. For this and other reasons there is little reuse of water in the tanning industry.

The following tabulation gives data on water utilization by the leather tanning and finishing industry as reported in the 1963 census of manufacturers (7).

Water use:	Water quantity, bgy
Intake	15.
Reuse	Negligible.
Consumption	do.

Significant indicators of water quality

The chemical composition of the water is important in producing high quality leather. For some processes, such as the finishing of leather, distilled or demineralized water is best. The microbiological content of the water is equally important, but this can be controlled by use of disinfectants. The quality requirements at point of use are shown in table V–21.

Water treatment processes

Most tanning and leather product industries are located in urban areas and use public water supplies or ground water. A few tanneries use surface supplies. Such waters are usually chlorinated. They may also need additional treatment, such as clarification and iron and manganese removal.

A limited volume of water, whether from the public water supply or company-owned systems, may be softened, distilled, or demineralized.

TABLE V–21. Quality Requirements of Water at Point of Use by the Leather Tanning and Finishing Industry (SIC 3111)

[Unless otherwise indicated, units are mg/l and values that normally should not be exceeded. Quality of water prior to the addition of substances used for internal conditioning.]

Characteristic	Tanning processes	General finishing processes	Coloring
Alkalinity ($CaCO_3$)	(1)	(1)	(1)
pH, units	6.0–8.0	6.0–8.0	6.0–8.0
Hardness ($CaCO_3$)	150	(3)	(3, 4)
Calcium (Ca)	60	(3)	(3, 4)
Chloride (Cl)	250	250	(4)
Sulfate (SO_4)	250	250	(4)
Iron (Fe)	50	0.3	0.1
Manganese (Mn)	(5)	0.2	0.01
Organics: Carbon chloroform extract	(5)	0.2	(5)
Color, units	5	5	5
Coliform bacteria	(6)	(6)	(6)
Turbidity	(5)	(5)	(5)

[1] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

[2] Lime softened.

[3] Zero, not detectable by test.

[4] Demineralized or distilled water.

[5] Concentration not known.

[6] 1962 U.S. Public Health Service Drinking Water Standards, Pub. 956 (8).

NOTE.—Above values based on Part 23, ASTM book of standards (1); APHA standard methods for examination of water and wastewater, (5).

Part VII. cement industry (SIC 3241)

About 58 percent of current cement manufacture is by the wet process requiring an estimated 16 bgy (1966).

Quality requirements for process water in the cement manufacturing industry are not rigorous, although they are somewhat more restrictive than those of mixing water for concrete. Surface and ground waters and public water supplies are used. Treatment is usually not required.

A listing of the quality of surface waters that have been used is presented in table V–22. Quality requirements for water at point of use for the hydraulic cement industry are indicated in table V–23.

TABLE V–22. Quality Characteristics of Surface Waters That Have Been Used by the Hydraulic Cement Industry (SIC 3241)

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.]

Characteristic	Concentration	Characteristic	Concentration
Acidity ($CaCO_3$)	([1])	Iron (Fe)	1.8
Alkalinity ($CaCO_3$)	240	Manganese (Mn)	5
Chemical oxygen demand (O_2)	([2])	Organics: Carbon tetrachloride extract	1
Coliform bacteria (count/100 ml)	([2])	pH, units	6.9–8.8
Color, units	([2])	Silica (SiO_2)	16
Hardness ($CaCO_3$)	500	Dissolved solids	1,120
Calcium hardness ($CaCO_3$)	150	Suspended solids	200
		Sulfate (SO_4)	235
		Chloride (Cl)	100

[1] Zero, not detectable by test.

[2] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

NOTE.—Concentrations are based on limited data. Application of the above values should be based on Part 23, ASTM book of standards (1) or APHA Standard methods for the examination of water and wastewater (5).

TABLE V–23. Quality Requirements of Water at Point of Use for the Hydraulic Cement Industry (SIC 3241)

[Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown. Quality of water prior to addition of substances used for internal conditioning.]

Characteristic	Concentration	Characteristic	Concentration
Acidity ($CaCO_3$)	([1])	Organics: Carbon tetrachloride extract	1
Alkalinity ($CaCO_3$)	400	Iron (Fe)	25
Chemical oxygen demand (O_2)	([2])	Manganese (Mn)	0.5
Coliform bacteria, (count/100 ml)	([2])	pH, units	6.5–8.5
Color, units	([2])	Silica (SiO_2)	35
Hardness ($CaCO_3$)	([2])	Dissolved solids	600
Calcium hardness ($CaCO_3$)	([2])	Suspended solids	500
		Sulfate (SO_4)	250
		Chloride (Cl)	250

[1] Zero, not detectable by test.

[2] Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered.

NOTE.—Concentrations are based on limited data. Application of the above values should be based on Part 23, ASTM book of standards (1) or APHA Standard methods for the examination of water and wastewater (5).

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